SURVIVAL AND SUMMER HABITAT SELECTION OF MALE GREATER SAGE-GROUSE (*Centrocercus urophasianus*) IN SOUTHWESTERN MONTANA

by

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APPROVAL

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the Division of Graduate Education.

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This work is dedicated to my grandma, Jessie Cathers. She lived her life with grace, humility, and, above all, unwavering love and respect for the people around her. She saw the unique gifts of each member of my family, and encouraged each of us to follow our own paths in life. She was so excited when my path led to Montana, and proud that her daughters and granddaughters have made the most of opportunities she never thought possible for women. She is truly one of my heroes and I miss her deeply. I can only hope to be half the person my Grandma Jess was.

I love you, Grandma.

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ABSTRACT

During the 20th century, Greater Sage-Grouse (*Centrocercus urophasianus*) populations in North America have declined by 69-99%. In southwest Montana little is known about the factors leading to declines in sage grouse populations; as a result, there are strong concerns regarding sage grouse population trends and habitat quality. I used radio-marked male sage grouse to obtain known-fate survival data and provide locations for habitat analyses. The objectives of the study were (1) to estimate survival rates of marked birds, and (2) to characterize the habitat used by sage grouse in southwestern Montana and compare it with available habitat. I used known-fate data to estimate annual survival, and I measured habitat attributes associated with aerial locations of instrumented sage grouse (use sites) and a series of randomly chosen locations within each study site (available sites). From 2001-2005, 45 male sage grouse were instrumented and monitored. The estimated annual survival rate was 0.34 (95% CI: 0.21 to 0.47). In 2004 and 2005, I measured vegetation characteristics at 78 habitat plots (43 used, 35 available). I used logistic regression to model habitat selection; grass height was an important predictor of use, but the negative relationship between the probability of a site being used and grass height was opposite of what I had predicted. Further research is needed to determine whether this behavior is adaptive. An important predictor of use in my exploratory analysis was solar radiation index (SRI). The negative effect of SRI on habitat selection may have been a result of sampling only during summer daylight hours, and SRI may have acted as a proxy for microsite temperature. Further research is needed over a wide variety of conditions to determine how habitat components relate to or interact with each other, habitat selection by sage grouse, and survival of sage grouse.

INTRODUCTION

Decreasing numbers of birds, mammals, and plants are closely tied to growing human populations and increasing population densities (Kerr and Currie 1995, McKee et al. 2003, Thompson and Jones 1999). Anthropogenic activities such as the introduction of non-native species and pathogens threaten avian populations through competition & aggression (e.g. House Sparrow, *Passer domesticus*; Gowaty 1984), predation (e.g. domestic cats; Lepczyk et al. 2003), and disease (e.g. avian malaria, *Plasmodium relictum*; Warner 1968). The most pervasive threat to species is loss and degradation of natural habitat (Sidle and Bowman 1988, Balmford and Bond 2005); in North America, sagebrush (*Artemisia* spp.) habitats are among the most rapidly disappearing (Knick et al. 2003). Livestock grazing (Schulz and Leininger 1990, Crowley and Connelly 1997, Beck and Mitchell 2000), conversion of sagebrush steppe to range and cropland with herbicides, plowing, and irrigation (Martin 1970, Swenson et al. 1987, Harrington 2002), fire and changes in fire regime (Benson et al. 1991, Wrobleski 1999, Nelle et al. 2000, Wambolt et al. 2001), and oil and gas development (Knick et al. 2003) all contribute to degradation or outright loss of sagebrush habitats. Many of these land use practices compound each other. For example, the non-native species cheatgrass (*Bromus tectorum*), introduced in the late 19th century (Mack 1981), creates a continuous fine fuel leading to increased fire frequency which, in turn, decreases sagebrush (West and Young 2000). At the other extreme, reduction of fine fuels (due to livestock grazing) and fire suppression on public lands has led to greatly increased fire intervals allowing conifers (*Juniperus* spp.) to encroach on and compete with sagebrush (Miller and Rose 1999).

The western United States is home to eight endemic sagebrush obligate vertebrate species, along with approximately 95 bird, 92 mammal, 58 reptile, and hundreds of invertebrate species that use sagebrush habitats extensively (Welch 2005). Among sagebrush obligate species, populations of Pygmy rabbits (*Brachylagus idahoensis*; Thines et al. 2004), Brewer's Sparrow (*Spizella breweri*), and Sage Sparrow (*Amphispiza belli*; Knick et al. 2003) are declining as a result of habitat loss or degradation. Greater Sage-Grouse (*Centrocercus urophasianus*; hereafter, sage grouse) have become the flagship species of sagebrush-steppe and been the greatest focus of conservation concern in sagebrush habitats. Sage grouse, the largest North American grouse species, is a charismatic, iconic, and hunted species that can be found in sagebrush habitats throughout the western United States and Canada (Aldrich 1963, Johnsgard 1973, Connelly and Braun 1997, Schroeder et al. 1999) and is a major focus of wildlife management agencies in western North America. Sage grouse are listed as a Sensitive Species by the US Department of Agriculture Forest Service (USFS) in Regions 1,2,4,5, and 6 (USDA Forest Service 2005) and by the US Department of Interior Bureau of Land Management (BLM) in California, Colorado, Idaho, Montana, Nevada, Utah, and Wyoming (USDI Bureau of Land Management 2005). In Washington, sage grouse have been listed as threatened under the Washington Fish and Wildlife Commission since 1998, and the Columbia Basin population has been a candidate species under the Endangered Species Act since 2001 (Washington Department of Fish and Wildlife 2004). Sage grouse are also a Priority Level I Species of Special Concern according to Montana Partners in Flight (Montana Partners in Flight 2000), and a Canadian Species at Risk (extirpated in British Columbia, endangered in Alberta and Saskatchewan; COSEWIC 2005). For much of the 20th century, sage grouse populations in North America have declined by 69-99% (USFWS 2000) and now occupy only approximately 56% of their historic range (Fig. 1; Schroeder et al. 2004). As a result of this concern, many studies have centered on this declining endemic species.

Numerous studies of sage grouse habitat use or selection and population dynamics have been focused in areas such as the Great Basin, eastern Idaho, and central Montana where the elevation is generally below 2000 m (Dalke et al. 1960, Wallestad 1975, Ellis et al. 1989). However, populations exist at elevations above 2000 m and may face distinct challenges such as longer, and potentially harsher, winters. Moynahan et al. (2006) found that at ~800 m above sea level, deep snow (> 1.2 m) combined with cold temperatures (-3° to -47° C) led to a marked decrease in over-winter monthly survival rates of female sage grouse (from 0.986 in a mild winter to 0.913 in a severe winter). Southwest Montana offers a unique study opportunity of a small sage grouse population in a mosaic of forest and sagebrush habitats at higher elevations (1850-2850 m,

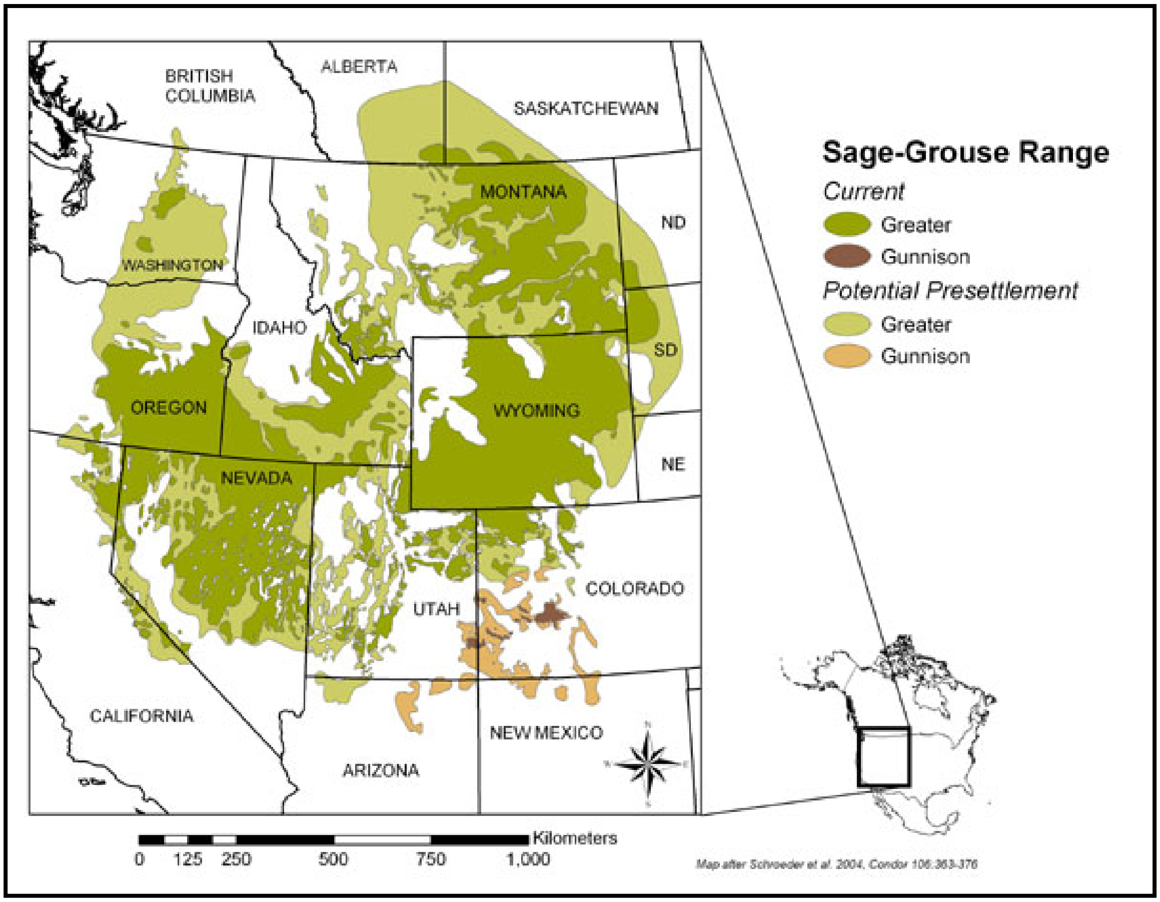


Figure 1. Historic and current range of sage grouse (Centrocercus spp.) in western North America illustrating the decline in the species' range from presettlement to present. [credit: USGS/Fort Collins Science Center]

Roscoe 2002). In southwest Montana little is known about the factors leading to declines in sage grouse populations (Roscoe 2002), but most of the pressures on sagebrush habitat discussed above are present. Much of the sagebrush habitat has been fragmented due to patchy land ownership, and is being used for livestock grazing and hay production (Roscoe 2002). In the 1950's and 1960's, agri-chemicals, chaining, plowing, and seeding were used to convert sagebrush steppe for livestock grazing and hay production (Martin 1970, J. W. Roscoe, BLM, pers. comm.). Presently, there are strong concerns regarding sage grouse population trends and habitat quality in southwest Montana.

Conversion and degradation of habitat likely contribute most to sage grouse population declines. Understanding sage grouse habitat selection is crucial to protecting and managing the habitats that are vital to the species survival. Information regarding habitat needs and quality are of great use to management agencies and private landowners because they have a direct effect on land use, which indirectly affects wildlife through habitat quality. By measuring and characterizing habitat used by sage grouse (e.g. percent shrub cover, shrub density, and percent herbaceous cover), managers have a better understanding of which habitat features to protect and/or improve. Habitat amount and quality affect the dynamics of wildlife populations (Wiegand et al. 2005, Soule 1986), thus management strategies aimed at improving or maintaining sage grouse habitats should lead to increased sage grouse populations.

In this study I focused on habitat selection and survival of male sage grouse in southwestern Montana to provide this needed information to management agencies, and improve understanding of sage grouse life history and patterns of habitat use in a region that has been little studied. I used radio-marked sage grouse to obtain known-fate survival data and provide locations for habitat analyses. The objectives of the study were (1) to estimate survival rates of marked birds and compare them to those found for sage grouse in other areas, (2) to characterize the habitat used by sage grouse in southwestern Montana and compare these data with the attributes of available habitat within the study area, and (3) to compare habitat characteristics from my study area with findings from other areas, and with the recommendations of Connelly et al. (2000).

Comparisons of field data with existing literature can lead to a better understanding of a particular system. By examining the similarities and differences of, for example, habitats, predator communities, landscape characteristics, and management strategies of different populations of a certain species, researchers and land managers can assess different aspects of a population and its environment. Hypotheses regarding the effects of certain habitat or landscape characteristics on population dynamics can be proposed and tested, or the effectiveness of different management strategies can be examined. Considering the demographics of a species over a wide range of conditions can lead to better management strategies and a better understanding of a species' needs.

STUDY AREA

Data were collected on three sites in Beaverhead County, Montana (Fig. 2): Big Sheep Creek Basin (BSC), Horse Prairie (HP), and Centennial Valley (CV). These three sites were chosen because they supported breeding populations of sage grouse that were of concern to the local management agencies due to declining numbers and degraded habitat. I collected data in BSC and HP from 2001 to 2005; the CV site was added as a third study site in 2005 because a new lek was found and sage grouse began using two previously inactive historic leks again. The primary land use on all three sites was livestock grazing with some hay production in Horse Prairie. Average annual precipitation for the three sites ranged from 20-56 cm (Montana Natural Resource Information System 2006) with BSC receiving the most precipitation and HP the least.

BSC (~6,000 ha) was located ~25 km west of Lima, Montana. BSC ranged in elevation from 2000-2850 m and was bordered by the Tendoy Mountains to the north and east and the Continental Divide to the west and south; it connected to the Medicine Lodge Drainage in Idaho. The valley floor (riparian areas) predominantly consisted of privately owned lands interspersed with some public (BLM) land. The uplands adjacent to the private lands were managed by the BLM, and higher elevation lands were managed by the USFS (Beaverhead-Deerlodge National Forest). The dominant shrubs were low sagebrush (*Artemisia arbuscula*), mountain big sagebrush (*A. tridentata*

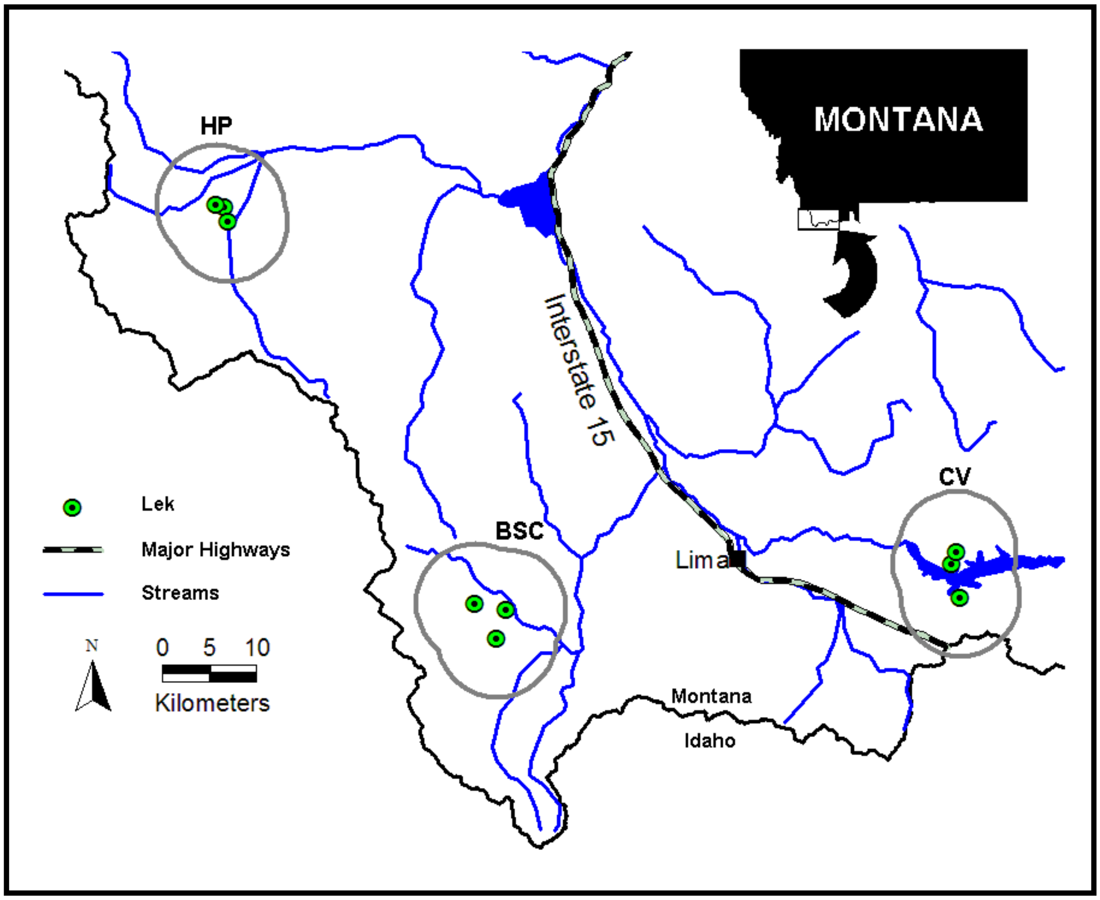


Figure 2. Locations of three study sites of a sage grouse study conducted in southwest Montana. Circles around leks are 6.3-km radius buffers (Connelly et al. 2000) defining each study site. Abbreviations denote sites (BSC: Big Sheep Creek, CV: Centennial Valley, HP: Horse Prairie).

vaseyana), and black sagebrush (*A. nova*). Other vegetation common to BSC were rabbitbrush (*Chrysothamnus* spp.), horsebrush (*Tetradymia* spp.), willow (*Salix* spp.), Idaho fescue (*Festuca idahoensis*), bluebunch wheatgrass (*Agropyron spicatum*), and a variety of perennial forbs. The sage grouse population in BSC was thought to migrate between summer habitat in BSC and winter habitat across the Continental Divide in Idaho (Roscoe 2002), but over the course of this study, I found that some of the sage grouse stayed in BSC year-round.

HP (~6,000 ha), ~60 km southwest of Dillon, Montana, ranged in elevation from 1850-2750 m and encompassed the area from Grant, Montana west to Lemhi Pass and south to Bannock Pass. Land at lower elevation was a mosaic of privately-owned and BLM-managed lands, the mid- and high-elevation lands were managed by the BLM and USFS (Beaverhead-Deerlodge National Forest), respectively. Dominant plants were Wyoming big sagebrush (*Artemisia tridentata wyomingensis*), three-tip sagebrush (*A. tripartita*), rabbitbrush, Idaho fescue, and a variety of perennial forbs. The sage grouse of HP were yearlong residents.

The CV site (~9600 ha), in the western end of the Centennial Valley, was ~25 km east of Lima, Montana and ranged in elevation from 2022-2558 m. CV was bordered on the north by the Clover Divide, on the south by Interstate-15 and the Continental Divide, and on the west by the Lima Dam. Lima Reservoir (~1900 ha) was located in the center of the study area; most of the land surrounding the reservoir was managed by the BLM and the State of Montana, but some private land was mixed in with and adjacent to the public land. Dominant plants were three-tip sagebrush, low sagebrush, black sagebrush, rabbitbrush, horsebrush, Idaho fescue, wheatgrasses (*Agropyron* spp.), and a variety of perennial forbs. Telemetry data from this study indicated the CV sage grouse were migratory, moving over the Continental Divide into Idaho during the winter.

METHODS

My initial goal was to study breeding season ecology and nesting and brood-rearing habitat, but, due to a paucity of females in the study area and extreme difficulty at obtaining a sample of females for study, I changed my focus to survival and habitat selection of males. Sage grouse were captured on or near leks from mid-March through May 2001 through 2005. I attempted to capture sage grouse using spotlighting (Giesen et al. 1982, Wakkinen et al. 1992b), walk-in traps (Giesen et al. 1982, Leonard et al. 2000, Connelly et al. 2003), and rocket-netting (Giesen et al. 1982, Wunz 1987). All birds trapped were marked with Advanced Telemetry Systems (ATS, Isanti, MN) model A4060 necklace-style radio transmitters (Amstrup 1980, Autenrieth 1981). The transmitters had a 4-hour mortality circuit, weighed 20 g each (<5% of body weight), and had an expected battery life of 340 days. Each bird was also marked with an individually numbered aluminum leg band (National Band and Tag Company, Newport, KY).

Radio-marked birds were monitored using aerial telemetry surveys conducted every 2 – 4 weeks (variation due to weather; Mountain Air Research, Inc., Driggs, ID) from May through September and once per month from October through April in 2001-2005 (except 2004). In 2004, very few birds were marked so most telemetry was done from the ground with telemetry flights done as needed to locate birds not found from the ground. When a transmitter's signal switched to mortality mode, the transmitter was recovered as quickly as possible and the location was recorded. I determined the cause of mortality when possible based on the state of the carcass (i.e. bones that were stripped but intact were signs of raptor depredation while crushed bones were attributed to mammalian predators). All locations were recorded in Universal Transverse Mercator (UTM) coordinates (zone 12T) and plotted on 1:24,000 quadrangle maps of the study sites.

I also monitored leks by conducting lek counts in late-March and April using the recommendations of Jenni and Hartzler (1978). Although lek counts provide an indication of a population's status, these numbers should not be used as an absolute measure of population size (Connelly et. al. 2000). Beck and Braun (1980) stated that large variation exists in counts at a single lek from one day to the next; therefore, I used lek-count data to obtain general information about the numbers of males and females attending the leks at which I captured and marked sage grouse.

Many habitat studies have not defined or differentiated habitat *use* and habitat *selection* (Jones 2001). Habitat use can be defined as the pattern of habitat characteristics used by a species or population that describes the distribution of individuals across a given landscape while habitat selection is a process in which individuals choose certain habitats over others presumably based on an increase in fitness (Hutto 1985, Block and Brennan 1993). In this study I examined habitat selection with a use versus availability design. Keating and Cherry (2004) cautioned that in use versus availability designs, available habitat may be contaminated with habitats that were actually used. I know this occurred in this study (sage grouse droppings were found in areas defined as available habitat), but this resulted to underestimation of the strength of habitat selection by sage grouse. According to Jones (2001), habitat selection studies should incorporate demographic information to determine whether selection of certain habitats was adaptive. I was unable to tie habitat selection with fitness; although I could not determine whether natural selection was occurring in this study, I did demonstrate habitat selection at the individual level (Johnson 1980).

I measured habitat attributes associated with aerial locations of instrumented sage grouse (use sites) and a series of randomly chosen locations within each study site (available sites). Use sites were chosen at random from aerial locations gathered from May-August of 2001-2005 because there was not adequate time to sample all points, and were constrained by accessibility (some land owners would not allow us to access their land and some locations were inaccessible due to topography and time). The UTM coordinate for each chosen aerial location was used as the center for a use vegetation plot. I measured telemetry error using aerial estimates of mortality locations and matched ground locations from transmitter retrievals. I used a 95% confidence ellipse to describe precision and mean linear error to describe accuracy of aerial telemetry locations. Available habitat was identified using two criteria in a geographic information system (GIS): a satellite imagery land cover classification system (SILC 3) layer for southwest Montana and 6.3-km radius buffers (Connelly et al. 2000) around leks on which birds were captured (Fig. 3). The SILC 3 layer was

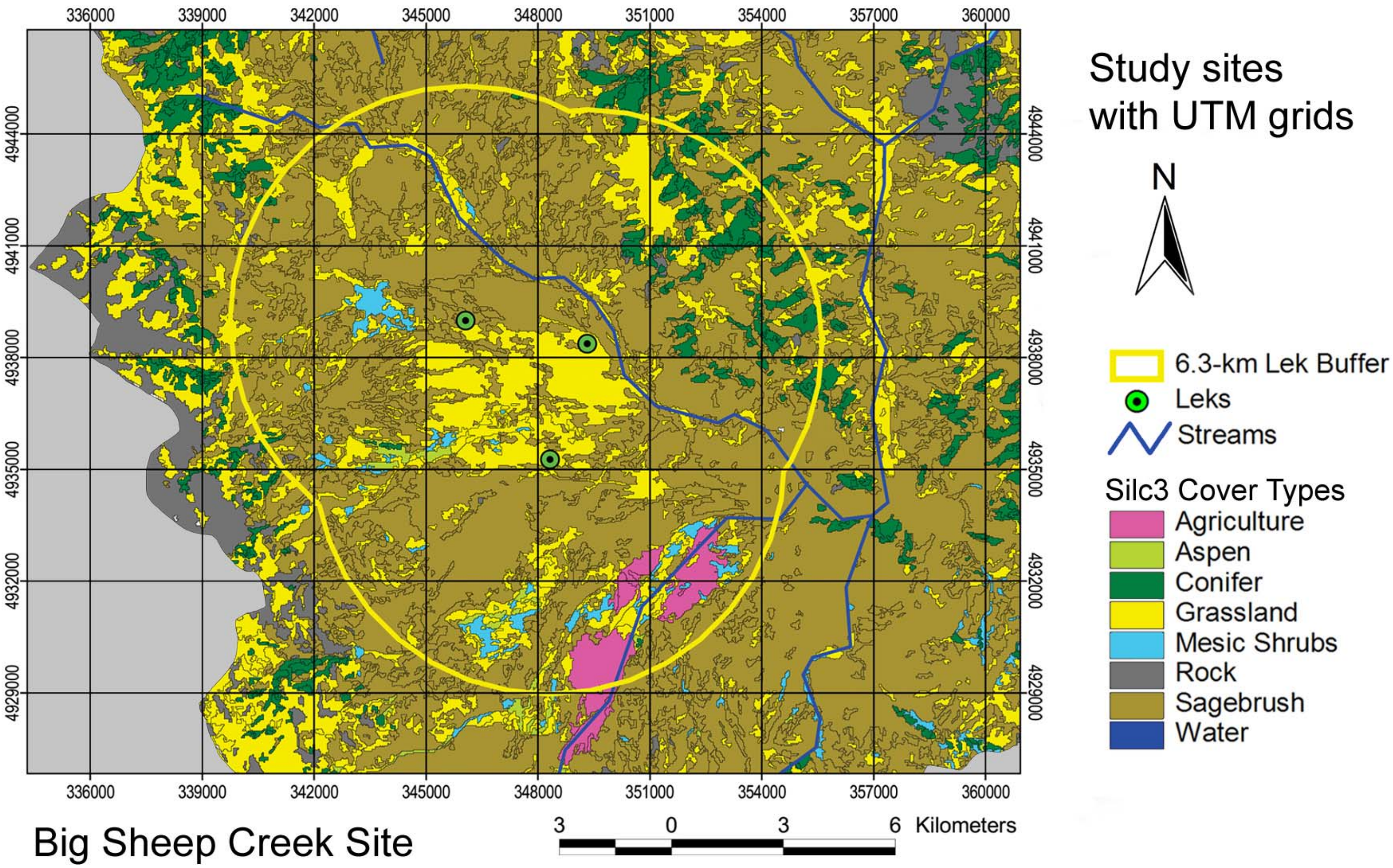
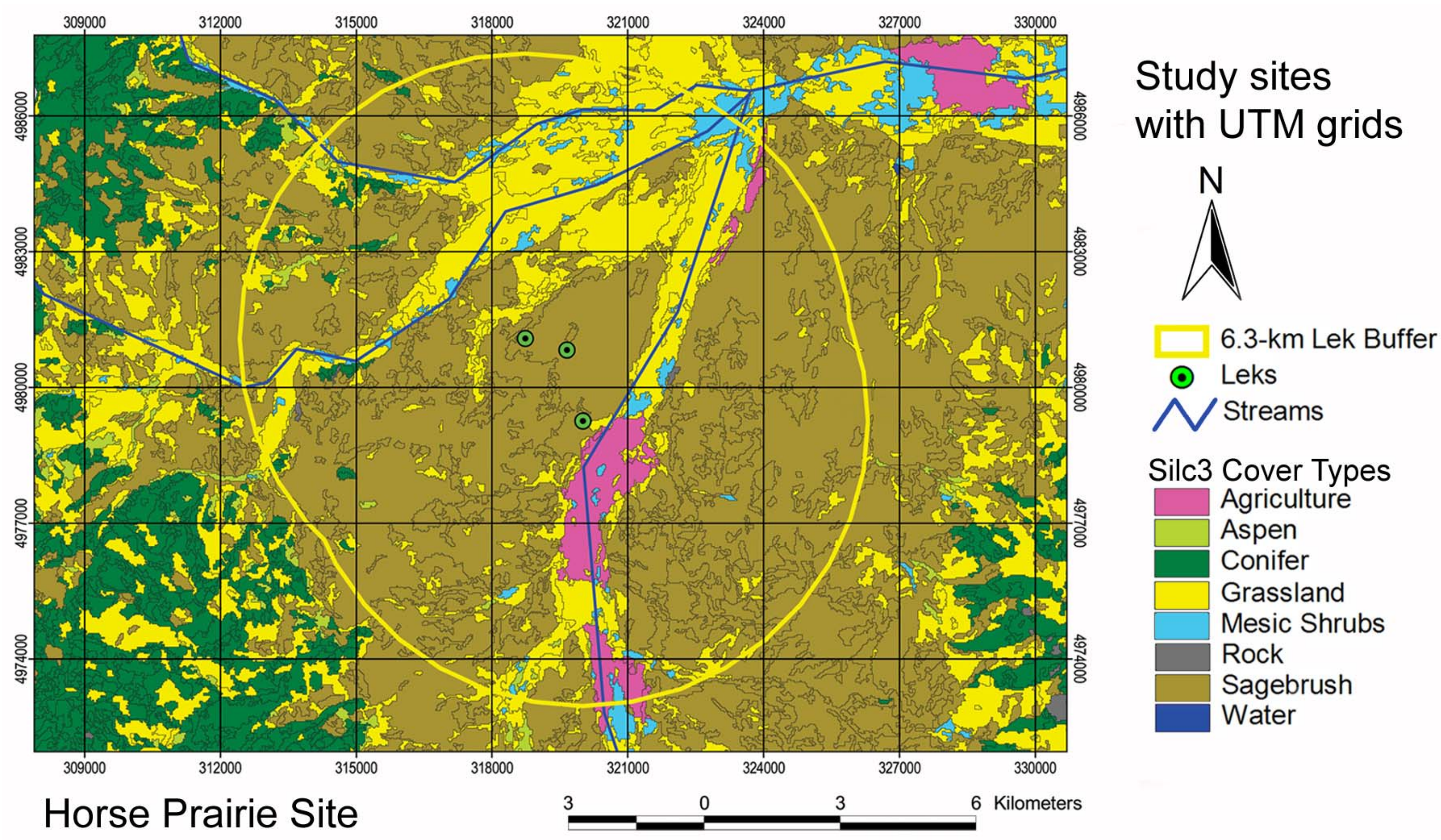


Figure 3. Maps of study sites using a satellite imagery land cover classification system (SILC 3) GIS layer for southwest Montana with 6.3-km radius lek buffers and a 3-km by 3-km UTM grid used in the selection of random points for measuring and characterizing available sage grouse habitat.



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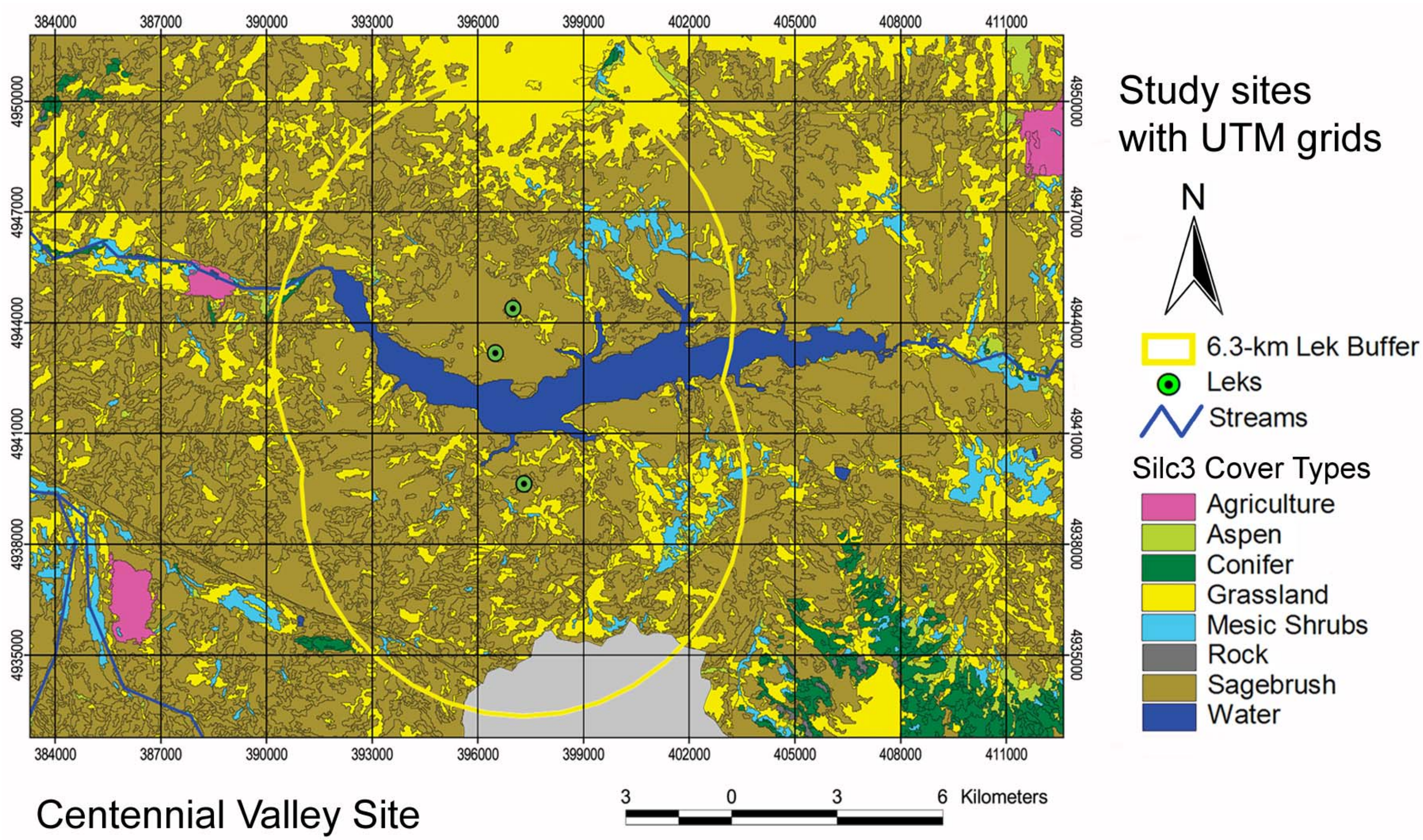

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developed by the USFS and the Wildlife Spatial Analysis Lab at the University of Montana to standardize land cover types across Region 1 of the USFS (Wildlife Spatial Analysis Lab 2001). I used 6.3-km lek buffers based on the monitoring protocols of the local management agencies which were developed from the average distance of sage grouse nests from the lek (Connelly et al. 2000). Within each lek buffer, a systematic grid with 3 km by 3 km quadrats was laid out; I chose quadrats of this size based on how many plots could logistically be measured during the study. For each quadrat, random UTM coordinates were generated to serve as the plot center; if the coordinate fell within a cover type suitable for sage grouse (according to Connelly et al. 2000) such as sagebrush/xeric shrubs (versus lodgepole pine or rock), I used the coordinate as the center for an available vegetation plot. If the coordinate did not occur in suitable sage grouse habitat, new random coordinates were generated until one did fall within suitable habitat.

I based much of the sampling protocol on the recommendations of Connelly et al. (2000), which were based on a review of current sage grouse research, because they were the most recent set of sage grouse management guidelines put forth by prominent sage grouse researchers. The sage grouse population and habitat monitoring protocols of the local management agencies also followed these guidelines, which allowed this study to fit within the framework of monitoring legally required of the agencies.

Habitat was sampled from mid-May to mid-August in 2004 and 2005 and several attributes were measured at each plot which served as potential covariates for my analyses. I measured habitat selection at the spatial scale of an individual within its home range (i.e. Johnson's third-order selection, Johnson 1980) and at a narrow temporal scale of summer (June-August) during daytime over two years of continuous drought. Each plot center was located using a hand-held Global Positioning System (GPS) unit, then six 30 m transects spaced 6 m apart were placed in approximately the north-south direction, resulting in a 30 m by 30 m vegetation plot (Fig. 4). Along each transect, line-intercept sampling was used to measure percent shrub cover (Canfield 1941), and belt transects (2 m by 30 m) to measure shrub density of mature shrubs (crown width ≥ 15 cm); these measurements were recorded for both live and dead shrubs.

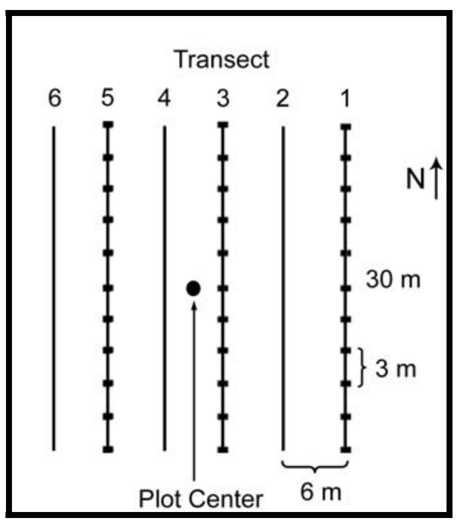

Figure 4. Diagram of used and available sage grouse habitat vegetation plots. All transects were used for line-intercept sampling and belt transects. Transects 1,3, and 5 were used for Daubenmire sampling and height measurements (hash marks). Slope and aspect were assessed at the plot center.

Herbaceous canopy cover was measured every 3 m along transects 1, 3, and 5 (due to time) using a 0.1 m^2 sampling frame (Daubenmire 1959). Shrub and grass heights were measured at each Daubenmire location. At each vegetation plot center, I also recorded slope and aspect. Attributes with multiple measurements in a plot (e.g. shrub height) were averaged for each plot. Connelly et al. (2003) stated that protocols for monitoring sage grouse habitat should be standardized allowing for direct comparisons between studies in different areas and years; density and height are direct measurements while cover can be estimated using several different techniques. I used line-intercept sampling with a plumb bob and excluded gaps in live foliage ≥ 3 cm to estimate shrub cover because it is highly accurate and repeatable compared to other methods of estimating cover (Wambolt et al. 2006). I used ocular estimates (Daubenmire method) to estimate herbaceous canopy cover because it is an efficient method of estimation (Higgins et al. 1994). The above metrics are commonly used in sage grouse and other range research, allowing for comparison to other studies (as suggested by Connelly et al. 2003). Most of the metrics were static over the course of the summer, however, herbaceous canopy cover and grass height measurements changed over the course of the summer due to seasonal growth.

Statistical Analyses

Survival

I used aerial telemetry data from 2001-2005 to estimate and model male sage grouse survival using a known-fate analysis (Kaplan and Meier 1958; Pollock et al. 1989 *a*,*b*); fates were determined using the mortality sensor of the radio transmitter. I considered the effects of season (winter, lekking, summer, hunting), year (2001-2005), and site (BSC, HP, CV) on survival; season and year were coded using indicator variables and site was coded as three groups in the input file. Seasons were defined based on biologically relevant periods during the year: winter: November 1 – March 14, lekking: March 15 – May 14, summer: May 15 – August 31, hunting: September 1 – October 31. I expected survival to vary by season due to different pressures on sage grouse during different times of the year. I thought survival would be lower during 1) the lekking season because males are more prone to predation at that time of year (Patterson 1952, Boyce 1990, Schroeder et al. 1999), and 2) during the hunting season because sage grouse may experience increased mortality during the hunting season (Bergerud 1985, 1988). I also expected survival to vary by site due to potential differences in habitat quality or predator community, and by year due to differences in weather or drought conditions, but I did not know how individual sites or years would affect survival (i.e. whether the coefficient would be negative or positive). I monitored birds in multiple years until they either died or their transmitter failed (malfunction or end of battery life). If a bird's transmitter failed, I censored that bird from the date of known failure; rarely a radio failed then began transmitting again, in these cases, the bird was censored during the period of malfunction and reentered the sample population at the first known date the radio resumed transmitting.

The intervals between telemetry survey flights varied, thus I modeled daily survival rate (DSR) using the known-fate module of program MARK with the logit link function (White and Burnham 1999). I developed eight *a priori* candidate models that considered constant survival over the entire study, variations by season, year, and site, and additive combinations of these predictors. The candidate model list was restricted to eight because I did not want to overparameterize the global model since this dataset included small sample sizes and all predictor variables were categorical. The small sample size bias-corrected version of Akaike's Information Criterion (AIC*c*) was used to compare models and model selection was based on the methods described by Burnham and Anderson (2002). I estimated overdispersion for the most general model using c-hat (model deviance divided by deviance degrees of freedom) because of possible lack of independence between individuals or heterogeneity in parameters (Burnham and Anderson 2002). I used c-hat to assess goodness-of-fit of the most general model and adjusted AIC*c* using quasi log-likelihood (QAIC*c*) if c-hat > 1. I exponentiated the DSR of the top model to estimate the survival rates over different periods of time (e.g. annual survival = DSR^{365}, monthly survival = DSR^{30}), then used the delta method to calculate the 95% confidence intervals (Cooch and White 2005).

Habitat selection

I expected habitat characteristics for use plots to differ from the random available plots. I predicted that characteristics from use plots would generally follow those outlined by Connelly et al. (2000). I used logistic regression with the logit link to model used and available habitat plots in R 2.2.1 (R Development Core Team, 2005). First, I developed additive *a priori* models using the linear forms of the logits of the predictors. I examined the correlations between all continuous variables. If two variables were correlated ($|r| \geq 0.6$), I used the variable that was most biologically relevant. The response variable for my analysis was plot type (use versus available), and the predictor variables were a combination of vegetation and topographic measurements taken in the field, and GIS data available from the state of Montana (Montana Natural Resource Information System 2006; Table 1). I compared the *a priori* models using AIC*c*. I also performed an exploratory analysis using combinations of variables not considered in the a priori analysis; no quadratic forms or interactions were suggested by Connelly et al. (2000), so none were evaluated. Goodness-of-fit was tested on the full model according to le Cessie and van Houwelingen (1991).

I thought habitat selection would follow a similar pattern for all three study sites and lacked adequate sample sizes within sites, so I did not include a variable for site. I expected the probability of a site being used by male sage grouse to increase with (1) more cover (i.e.higher shrub density, greater shrub cover, greater herbaceous canopy cover, and taller grasses; Wallestad and Schladweiler 1974, Ellis et al. 1989), (2) distance to roads (i.e. avoidance of roads; Forman and Alexander 1998), and (3) distance to power lines (i.e. avoidance of power lines due to the risk of collision or predation by perched raptors; Borell 1939, Rogers 1964, Graul 1980, Ellis 1984, 1987, Braun 1998, Rowland 2004). I thought the probability of use would decrease as both distance to water and solar radiation index increased (i.e. the regression coefficients would be negative). Sage grouse have been found to move toward areas with permanent water in mid- to late-summer coinciding with the desiccation of herbaceous vegetation (Klebenow 1969, Peterson 1970, Wallestad 1971, Wakkinen 1990, Fischer et. al. 1996). Studies have shown that to avoid heat stress some bird species roost in shaded areas (Coulombe 1971, Barrows 1981, Gill 1990); solar radiation index indicates areas with low levels of incident sunlight based on slope and aspect. Due to the timing of this study (daytime in June – August), I expected areas nearer to water and with lower SRI values to have a higher probability of use than those closer to water and with higher values of SRI.

Table 1. Potential predictor variables for logistic regression models of male sage grouse habitat selection in southwestern Montana. All shrub measurements were taken from mature plants (crown width ≥ 15 cm); cover and height measurements were averaged for each vegetation plot. Distance measurements and SRI were assessed for each vegetation plot center.

Variable	Description	Calculation	Predicted Effect (Slope)	Biological Reason [a]
TSC	Total Shrub Cover	% Cover of live and dead shrubs	$\beta > 0$	Cover needed for food and protection
TSD	Total Shrub Density	Density (shrubs/ha) of live and dead shrubs	$\beta > 0$	Higher density may provide increased protection
LSC	Live Shrub Cover	% Cover of live shrubs	$\beta > 0$	Cover needed for food and protection
LSD	Live Shrub Density	Density (shrubs/ha) of live shrubs	$\beta > 0$	Higher density may provide increased protection
THC	Total Herbaceous Cover	Mean total % canopy cover of grasses and forbs	$\beta > 0$	Herbaceous cover may provide food and protection
GHt	Grass Height	Mean height (to nearest cm) of grasses	$\beta > 0$	Taller grasses may provide increased protection
SHt	Shrub Height	Mean height (to nearest cm) of shrubs	$\beta > 0$	Taller shrubs may provide increased protection
Water	Distance to nearest Water	Distance in m, from GIS	$\beta < 0$	Riparian vegetation may provide food and protection during late summer
Road	Distance to nearest Road	Distance in m, from GIS	$\beta > 0$	Roads lack cover and may be travel corridors for predators
Power	Distance to nearest Power Line	Distance in m, from GIS	$\beta > 0$	Power lines provide perches for raptors (predators); act as barriers
SRI	Solar Radiation Index	Variable combining slope, aspect, and latitude (Iqbal 1983, see Appendix A)	$\beta < 0$	Increased heat, may be avoided during summer

[a] Protection refers to security from predators and/or weather.

RESULTS

Lek Attendance, Trapping, & Radiomarking

In 2003, the maximum number of males and females attending Simpson Creek lek (BSC) were ten and two, respectively, and five and zero at the Brenner lek complex (HP). In 2004, Simpson Creek lek moved approximately 2 km east of the historic lek center; twelve males and three females were the maxima in BSC, and twelve males and zero females were the maxima in HP. The maximum numbers of males in 2005 were 17 and 13 in BSC and HP, respectively. I did not observe any females attending any leks in 2005. In CV in 2005, the maximum numbers of males and females on the lek complex north of Lima Reservoir were 28 and 10 respectively; the lek to the south of the reservoir had maxima of 56 males and 21 females (Montana Department of Fish, Wildlife, and Parks, unpubl. data). In 2001 and 2002, the BLM trapped sage grouse using spotlighting and rocket-netting (J. Roscoe, pers. comm.). In 2003 and 2004, I used spotlighting (53 person nights in 2003 and 54 person nights in 2004) and walk-in traps (operated during April approximately twice per week in both years) in BSC and HP. All the birds were trapped using spotlighting; walk-in traps were unsuccessful in both years in both sites. In 2005, I used spotlighting in BSC and CV, and rocket-netting in BSC (38 person nights combined, trapping effort was lower in 2005 due to a personnel shortage). Again, all the birds were trapped using spotlighting; rocket-netting was unsuccessful. From 2001-2005, 45 male sage grouse were instrumented and monitored, this included 17 males in BSC, 11 males in HP, and 17 males in CV (Table 2).

Table 2. Sample sizes by year and site of male sage grouse in southwestern Montana. The first year of capture was 2001 for BSC and HP and 2005 for CV, capture was not attempted at all sites in all years (--). For each site, *n* = the number of birds captured in that year + the number of birds we continued to monitor from one year previous + the number of birds we continued to monitor from two years previous. The total number of birds monitored in that year are in parentheses.

		Year				
Site		**2001**	**2002**	**2003**	**2004**	**2005**
BSC	*n*	7	5+5+0 (10)	4+3+2 (9)	0+4+0 (4)	1+3+1 (5)
	Mortalities	2	5	5	0	2
	Failure[a]	0	0	2	2	0
HP	*n*	3	4+2+0 (6)	2+4+0 (6)	2+2+1 (5)	--+2+1 (3)
	Mortalities	1	2	3	2	3
	Failure[a]	0	0	0	0	0
CV	*n*	--	--	--	--	17
	Mortalities	--	--	--	--	8
	Failure[a]	--	--	--	--	0

[a] Failure indicates a malfunction of a transmitter or transmitter battery.

Survival

For 75 bird years, 35 birds died of various causes (Table 2); sources of mortality for most birds were difficult to assess as most were scavenged (usually, I found only the transmitter), but known sources of mortality included a 2001 BSC bird killed by a hunter and a 2003 BSC bird killed by ranch dogs. In many cases, I determined the source of mortality to be depredation (e.g. raptor, coyote), but in most cases, the cause of mortality could not be determined. I used known-fate data for 45 males to evaluate eight *a priori* models of male survival (Table 3). The estimate of overdispersion for the most general model (site+year+season) was 1.15. I used this value to adjust the model selection criterion and parameter estimates. The model most supported by the data was the model of constant survival (QAIC*c* weight = 0.82); all other models were >2 QAIC*c* units from the top model. The estimated daily survival rate for the top model was 0.997 (SE = 0.000502). The estimated annual survival rate (DSR^{365}) was 0.34 (95% CI: 0.21 to 0.47). The estimated seasonal survival rates were as follows: winter (DSR^{134}) was 0.67 (95% CI: 0.56 to 0.76), lekking (DSR^{60}) was 0.84 (95% CI: 0.77 to 0.88), summer (DSR^{108}) was 0.72 (95% CI: 0.63 to 0.80), and hunting (DSR^{61}) was 0.83 (95% CI: 0.77 to 0.88).

Table 3. Model selection results for all *a priori* models examining survival of male sage grouse in southwestern Montana from 2001 to 2005.

Model	**Delta[a] QAIC*c***	**QAIC*c* Weight**	**K**	**QDeviance**
S.[b]	0.00	0.82	1	74.14
S(site)	3.72	0.13	3	73.81
S(site+year)	7.23	0.02	7	69.04
S(site+season)	7.58	0.02	6	71.48
S(year+season)	8.91	0.01	8	68.61
S(site+year+season)	11.53	0.00	10	67.00
S(year)	97.29	0.00	5	163.26
S(season)	130.19	0.00	5	196.16

[a]Model selection based on c-hat = 1.15
[b]QAIC*c* for top model = 196.51

Habitat selection

In 2004 and 2005, I measured vegetation characteristics at 78 habitat plots (43 used, 35 available) over all three sites. The average dates plots were measured were as follows: Use—June 26 (range: June 3 – August 12), Available—July 29 (range: May 31 – August 18). When I examined the correlations (see Appendix B) between continuous covariates, I found two pairs of predictor variables to be highly correlated: total shrub cover (TSC) and live shrub cover (LSC; r = 0.965), and total shrub density (TSD) and live shrub density (LSD; r = 0.997). Accordingly, I chose to drop TSC and TSD from consideration and to use LSC and LSD because live shrubs provide cover and food, and are commonly used in the literature (Barnett and Crawford 1994, Fischer et al. 1996, Sveum et al. 1998, Nelle et al. 2000, Vander Haegen et al. 2000). I also found that two pairs of predictor of variables were moderately correlated: LSC and LSD (r = 0.638), and THC and GHt (r = 0.624); to choose which variable to use from each pair, I considered the AICc weights for the one-predictor models because there was not a defensible biological reason to choose one variable over the other (Table 4). Some may choose to use shrub cover (LSC) over density (LSD) for biological reasons; here, because these variables were extremely correlated, using one or the other did not change model selection results. Overall means for the habitat variables used in my analysis were as follows: live shrub density (LSD) was 12452.28 shrubs per ha (SE = 977.56),

Table 4. AIC*c* table for the one-predictor models used to determine which variable from each of two pairs of correlated variables to include in as predictors in the analysis of habitat selection by male sage grouse in southwestern Montana. See Table 1 for acronyms.

Model	**AIC*c***	**Delta AIC*c***	**AIC*c* Weight**	**K**
LSD	110.41	0	0.63	2
LSC	111.45	1.04	0.37	2
GHt	95.88	0	1	2
THC	111.15	15.27	0	2

grass height (GHt) was 18.48 cm (SE = 0.58), shrub height (SHt) was 28.50 cm (SE = 1.44), distance to water (Water) was 2212.92 m (SE = 185.90), distance to road (Road) was 483.71 m (SE = 54.25), distance to power line (Power) was 5936.87 m (SE = 607.35), and solar radiation index (SRI) was -0.10 (SE = 0.07). Detailed descriptive statistics can be found in Table 5.

I evaluated 11 *a priori* models and ten exploratory models (Table 6); the *a priori* models most supported by the data (combined AICc weight = 0.98) all included GHt, with the best-approximating model including GHt as the only predictor of habitat selection. I used the le Cessie-van Houwelingen goodness-of-fit test on the full model and did not find evidence of a lack of fit ($p = 0.575$). Male sage grouse were more likely to use areas with shorter grasses compared to available sites (i.e. the coefficient for grass height was negative, Table 7); the chance of use doubled with every three cm decrease in grass height (Figures 5, 6a, and 7a). Although two of the best models included LSD and one included SHt, the 95% confidence intervals for the coefficients of LSD and SHt

Table 5. Descriptive statistics for observed values of predictor variables used in the analysis of habitat selection of male sage grouse in southwestern Montana. Values are given for all habitat plots, habitat plots by plot type, and habitat plots by study site means. See Table 1 for acronyms.

ALL (n = 78)	LSD [a]	GHt [b]	SHt [b]	Water [c]	Road [c]	Power [c]	SRI
Mean	12452.28	18.48	28.50	2212.92	483.71	5936.87	0.72
Median	10958.33	17.83	28.71	1692.82	346.93	4652.70	0.71
S. D.	8633.57	5.15	12.73	1641.78	479.17	5363.98	0.08
Range	49472.22	28.86	59.33	7175.12	2485.73	22043.78	0.55
Minimum	55.56	8.61	0.73	3.98	6.33	67.84	0.38
Maximum	49527.78	37.47	60.06	7179.11	2492.07	22111.61	0.93
90% Decile	22025.00	25.71	45.13	4747.32	1212.77	13397.45	0.80
10% Decile	3438.89	12.57	13.80	610.87	33.06	523.43	0.66
PLOT TYPE							
Use (n = 43)	LSD [a]	GHt [b]	SHt [b]	Water [c]	Road [c]	Power [c]	SRI
Mean	13339.15	16.53	28.30	1876.57	374.22	5707.53	0.70
Median	11833.33	16.36	28.94	1530.84	281.58	2205.70	0.71
S. D.	9610.49	3.63	12.41	1337.05	336.57	6250.25	0.07
Range	49472.22	17.06	56.39	5737.64	1292.03	21928.98	0.47
Minimum	55.56	8.61	0.73	599.81	6.33	182.63	0.38
Maximum	49527.78	25.67	57.12	6337.46	1298.36	22111.61	0.85
90% Decile	24150.00	20.97	43.87	3816.26	913.45	14945.64	0.78
10% Decile	1811.11	11.79	14.02	783.30	28.87	449.06	0.66
Available (n = 35)	LSD [a]	GHt [b]	SHt [b]	Water [c]	Road [c]	Power [c]	SRI
Mean	11362.70	20.87	28.74	2626.15	618.23	6218.63	0.74
Median	10722.22	19.09	28.48	2301.88	437.35	5820.60	0.72
S. D.	7245.51	5.75	13.29	1891.35	588.44	4093.29	0.08
Range	38194.44	24.80	55.73	7175.12	2483.07	15918.29	0.33
Minimum	388.89	12.67	4.33	3.98	9.00	67.84	0.60
Maximum	38583.33	37.47	60.06	7179.11	2492.07	15986.13	0.93
90% Decile	18227.78	29.24	47.04	4898.02	1481.95	11245.38	0.82
10% Decile	3911.11	14.81	14.08	146.06	78.23	1033.65	0.67

[a] Shrubs per hectare
[b] Centimeters
[c] Meters

Table 5 (continued).

SITE							
BSC (n = 41)	LSD [a]	GHt [b]	SHt [b]	Water [c]	Road [c]	Power [c]	SRI
Mean	10363.82	17.40	29.48	2217.13	359.42	1986.94	0.72
Median	9277.78	15.52	30.61	1763.49	334.79	1197.58	0.71
S. D.	8487.43	5.83	12.67	1574.65	346.82	1751.91	0.07
Range	49472.22	27.04	52.79	7137.84	1644.33	6336.07	0.38
Minimum	55.56	10.42	0.73	41.26	11.35	67.84	0.56
Maximum	49527.78	37.47	53.52	7179.11	1655.68	6403.91	0.93
90% Decile	18000.00	25.82	46.06	4121.06	643.16	4609.49	0.79
10% Decile	666.67	12.27	13.97	678.48	29.86	401.62	0.66
HP (n = 13)	LSD [a]	GHt [b]	SHt [b]	Water [c]	Road [c]	Power [c]	SRI
Mean	10288.46	18.99	37.98	3218.31	483.39	8097.14	0.75
Median	9805.56	18.15	35.12	3188.33	211.73	7386.34	0.73
S. D.	4182.19	5.59	12.71	1882.99	690.63	5249.99	0.08
Range	15055.56	20.03	38.39	5590.50	2485.73	17050.39	0.28
Minimum	3944.44	8.61	21.67	746.96	6.33	596.93	0.63
Maximum	19000.00	28.64	60.06	6337.46	2492.07	17647.32	0.92
90% Decile	15377.78	25.98	56.65	5588.66	976.99	16324.89	0.84
10% Decile	6255.56	11.98	23.51	1085.86	27.48	2703.74	0.67
CV (n = 24)	LSD [a]	GHt [b]	SHt [b]	Water [c]	Road [c]	Power [c]	SRI
Mean	17192.13	20.05	21.69	1661.13	696.22	11514.52	0.71
Median	15263.89	19.83	19.26	1388.51	555.38	11528.24	0.71
S. D.	9015.04	2.93	8.85	1404.54	485.75	3700.51	0.09
Range	37944.44	10.64	32.09	5186.20	1598.04	16291.01	0.45
Minimum	638.89	15.64	7.42	3.98	9.00	5820.60	0.38
Maximum	38583.33	26.27	39.52	5190.18	1607.04	22111.61	0.83
90% Decile	28941.67	24.65	33.32	3719.10	1401.09	15049.57	0.79
10% Decile	9361.11	16.63	13.20	322.12	97.23	7393.59	0.66

[a] Shrubs per hectare
[b] Centimeters
[c] Meters

Table 6. Model selection results for all models examining habitat selection of male sage grouse in southwestern Montana from 2001 to 2005 (n = 78). See Table 1 for acronyms.

				Within Suite		Across Suites	
Model	**AICc**	**Model Deviance**	**K**	**Delta AICc**	**AICc Weight**	**Delta AICc**	**AICc Weight**
<u>Suite A: *a priori* models</u>							
GHt	95.88	91.72	2	0.00	0.52	0.10	0.18
LSD + GHt	97.07	90.75	3	1.19	0.29	1.30	0.10
LSD + GHt + SHt	98.10	89.55	4	2.22	0.17	2.32	0.06
LSD + GHt + SHt + Water + Road + Power + SRI	102.13	84.04	8	6.25	0.02	6.36	0.01
SRI	106.06	101.90	2	10.19	0	10.29	0
Road	106.20	102.04	2	10.32	0	10.43	0
Water	107.34	103.18	2	11.46	0	11.57	0
LSD	110.41	106.25	2	14.54	0	14.64	0
Power	111.29	107.13	2	15.41	0	15.52	0
SHt	111.45	107.29	2	15.57	0	15.67	0
LSD + SHt	112.58	106.25	3	16.70	0	16.80	0
<u>Suite B: exploratory models</u>							
GHt + SRI	95.76	89.45	3	0.00	0.3	0.00	0.19
GHt + Road	96.54	90.21	3	0.76	0.2	0.76	0.13
GHt + Power	96.56	90.23	3	0.78	0.2	0.78	0.13
GHt + SHt	97.16	90.84	3	1.39	0.15	1.39	0.10
GHt + Water	97.39	91.07	3	1.61	0.13	1.61	0.09
SRI + Road	103.58	97.26	3	7.80	0.01	7.80	0
SRI + Water	106.54	100.22	3	10.77	0	10.77	0
SRI + LSD	107.43	101.10	3	11.65	0	11.65	0
SRI + Power	108.07	101.75	3	12.30	0	12.30	0
SRI + SHt	108.21	101.88	3	12.43	0	12.43	0

considerably overlapped zero (Table 7). The probability of use increased with live shrub density and shrub height, but these coefficients were poorly estimated (Figures 6b, 7b, and 7c). I started the exploratory analysis with five models each

Table 7. Parameter estimates and confidence intervals for the best-approximating models of male sage grouse habitat selection in southwestern Montana from 2001 to 2005 (n = 78). See Table 1 for acronyms.

Model	Parameter	Coefficient Estimate	95% Confidence Interval	
			Lower	Upper
Suite A: *a priori* models				
GHt	Intercept	4.134	1.981	6.732
	GHt	-0.214	-0.354	-0.099
LSD + GHt	Intercept	3.818	1.541	6.498
	LSD	0.003	-0.003	0.010
	GHt	-0.218	-0.364	-0.100
LSD + GHt + SHt	Intercept	3.375	1.015	6.124
	LSD	0.004	-0.003	0.010
	GHt	-0.233	-0.384	-0.112
	SHt	0.024	-0.019	0.069
Suite B: exploratory models				
GHt + SRI	Intercept	8.006	2.556	14.925
	GHt	-0.200	-0.343	-0.083
	SRI	-5.737	-14.647	1.616
GHt + Road	Intercept	4.096	1.957	6.713
	GHt	-0.192	-0.335	-0.076
	Road	-0.077	-0.211	0.044
GHt + Power	Intercept	4.477	2.165	7.356
	GHt	-0.254	-0.429	-0.119
	Power	0.006	-0.004	0.017
GHt + SHt	Intercept	3.797	1.593	6.449
	GHt	-0.225	-0.368	-0.108
	SHt	0.020	-0.021	0.063
GHt + Water	Intercept	4.161	2.006	6.776
	GHt	-0.199	-0.344	-0.080
	Water	-0.013	-0.047	0.019

including GHt in combination with each predictor (e.g. GHt and Water) except LSD because this model was part of the *a priori* model suite. The coefficient of grass height was negative in all five models (Table 7); again indicating that male sage grouse were more likely to use areas with shorter grasses. The 95% confindence intervals for the coefficients for each of the other predictors overlapped zero (Table 7). However, the 95% confidence interval for SRI only slightly overlapped zero. I then continued the exploratory analysis with five more models each including SRI in combination with each predictor (except GHt). However, all of these models had ΔAIC*c* values (within the exploratory suite) of 7.80 or greater.

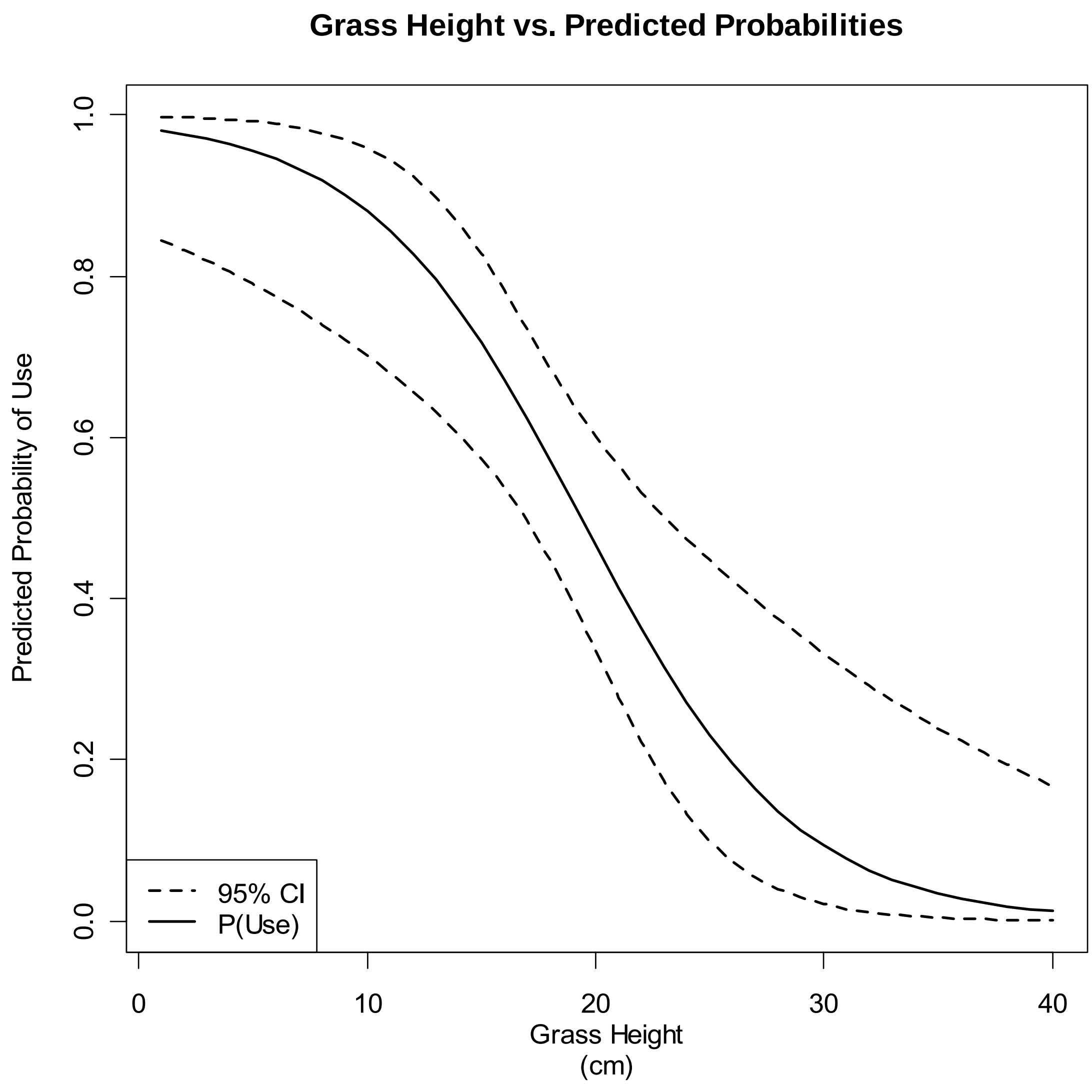

Figure 5. Plot of predicted (relative) probabilities of use for different values of GHt calculated using the top *a priori* model (GHt).

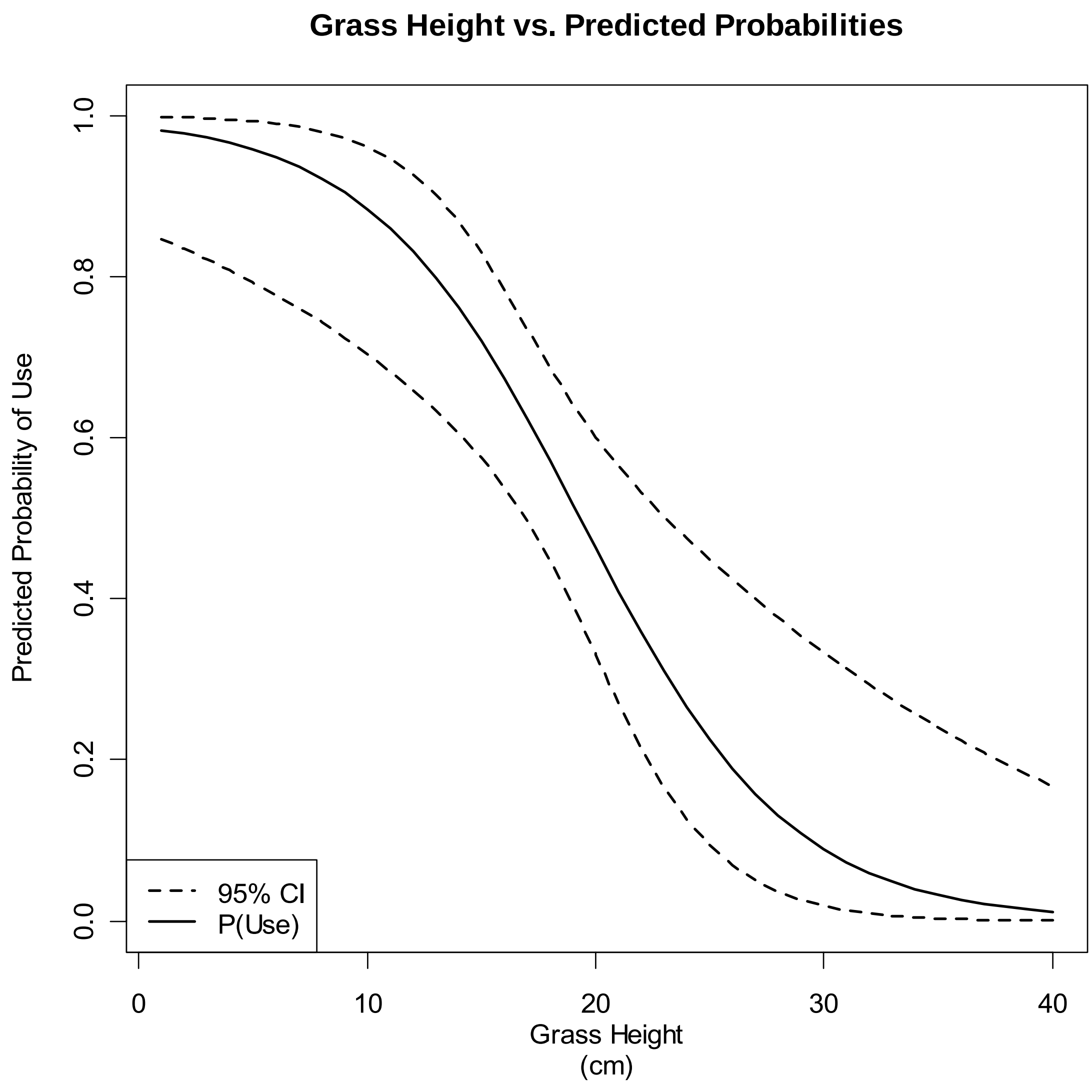

Figure 6a. Plot of predicted (relative) probabilities of use for different values of GHt calculated using the *a priori* model LSD + GHt. Values for GHt were allowed to vary while LSD was held constant at its mean of 12452 shrubs/ha.

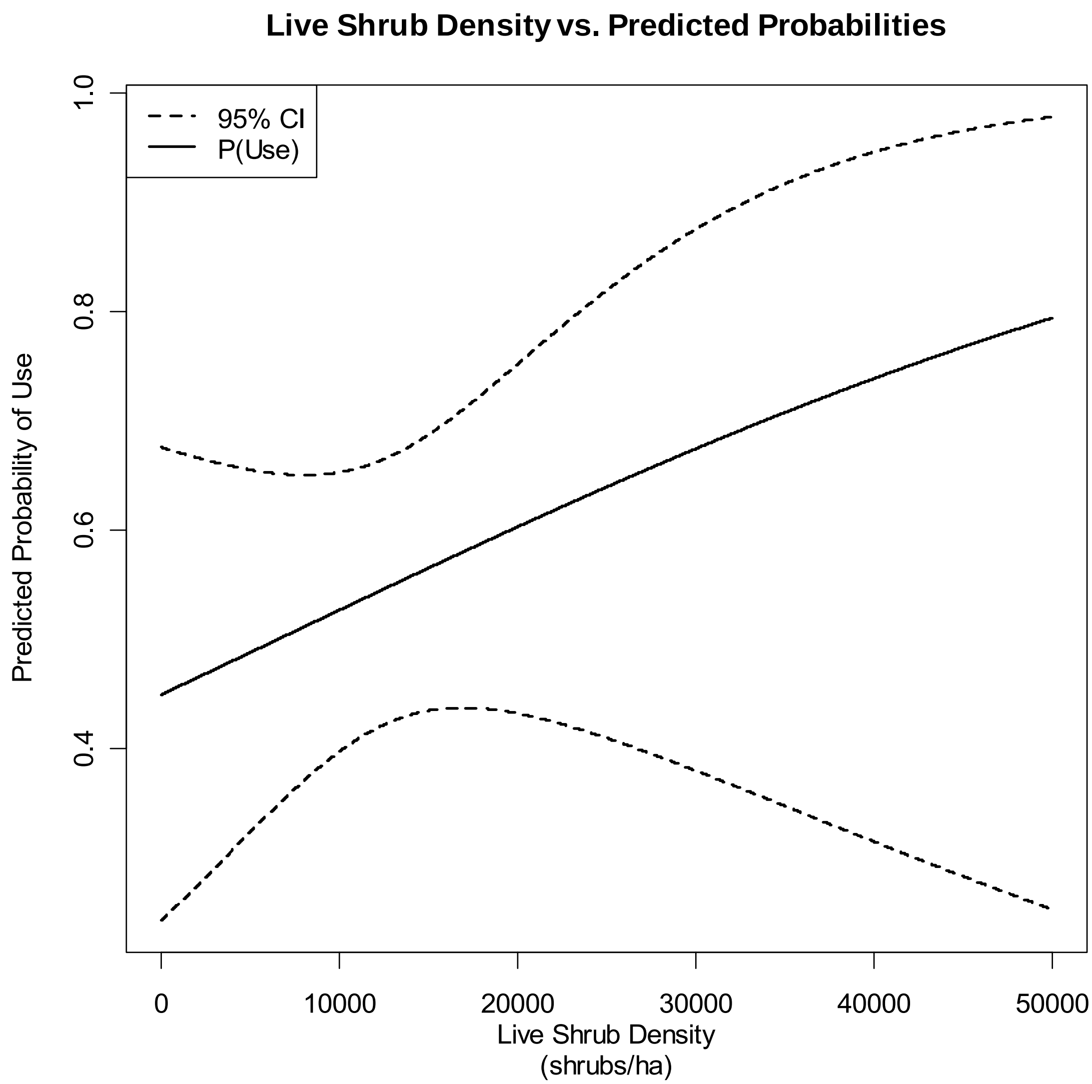

Figure 6b. Plot of predicted (relative) probabilities of use for different values of LSD calculated using the *a priori* model LSD + GHt. Values for LSD were allowed to vary while GHt was held constant at its mean of 18.48 cm.

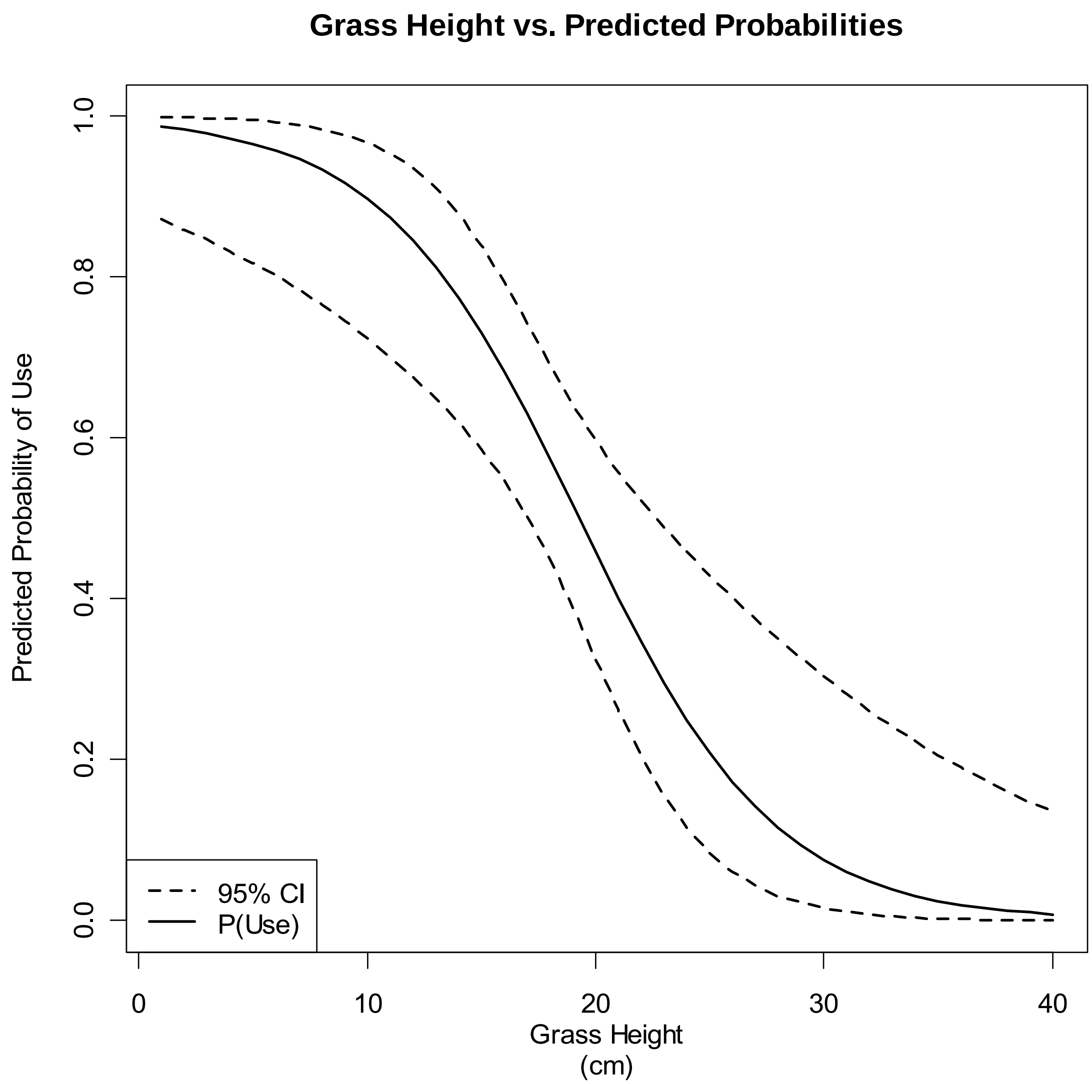

Figure 7a. Plot of predicted (relative) probabilities of use for different values of GHt calculated using the *a priori* model LSD + GHt + SHt. Values for GHt were allowed to vary while LSD and SHt were held constant at their respective means of 12452 shrubs/ha and 28.5 cm.

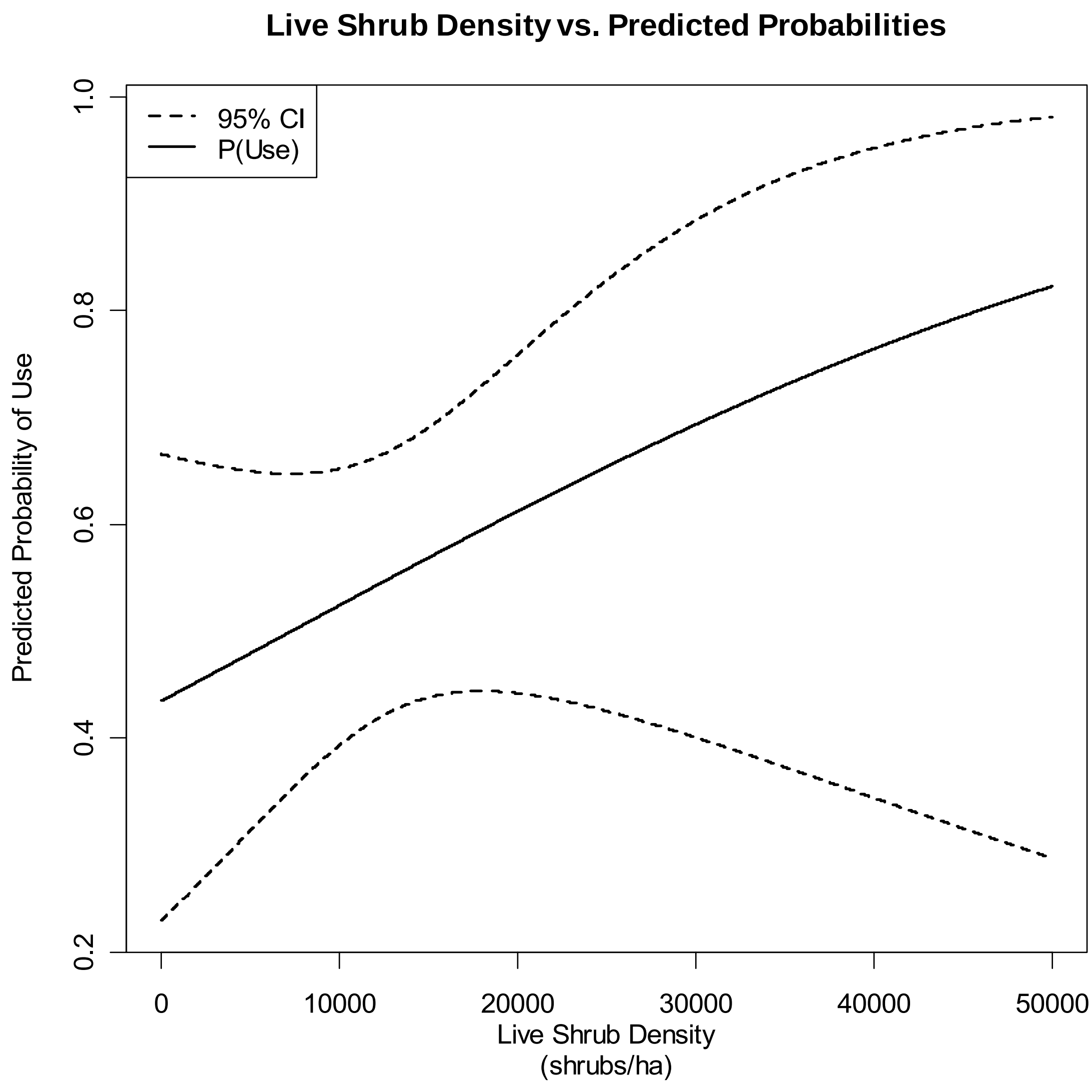

Figure 7b. Plot of predicted (relative) probabilities of use for different values of LSD calculated using the *a priori* model LSD + GHt + SHt. Values for LSD were allowed to vary while GHt and SHt were held constant at their respective means of 18.48 cm and 28.5 cm.

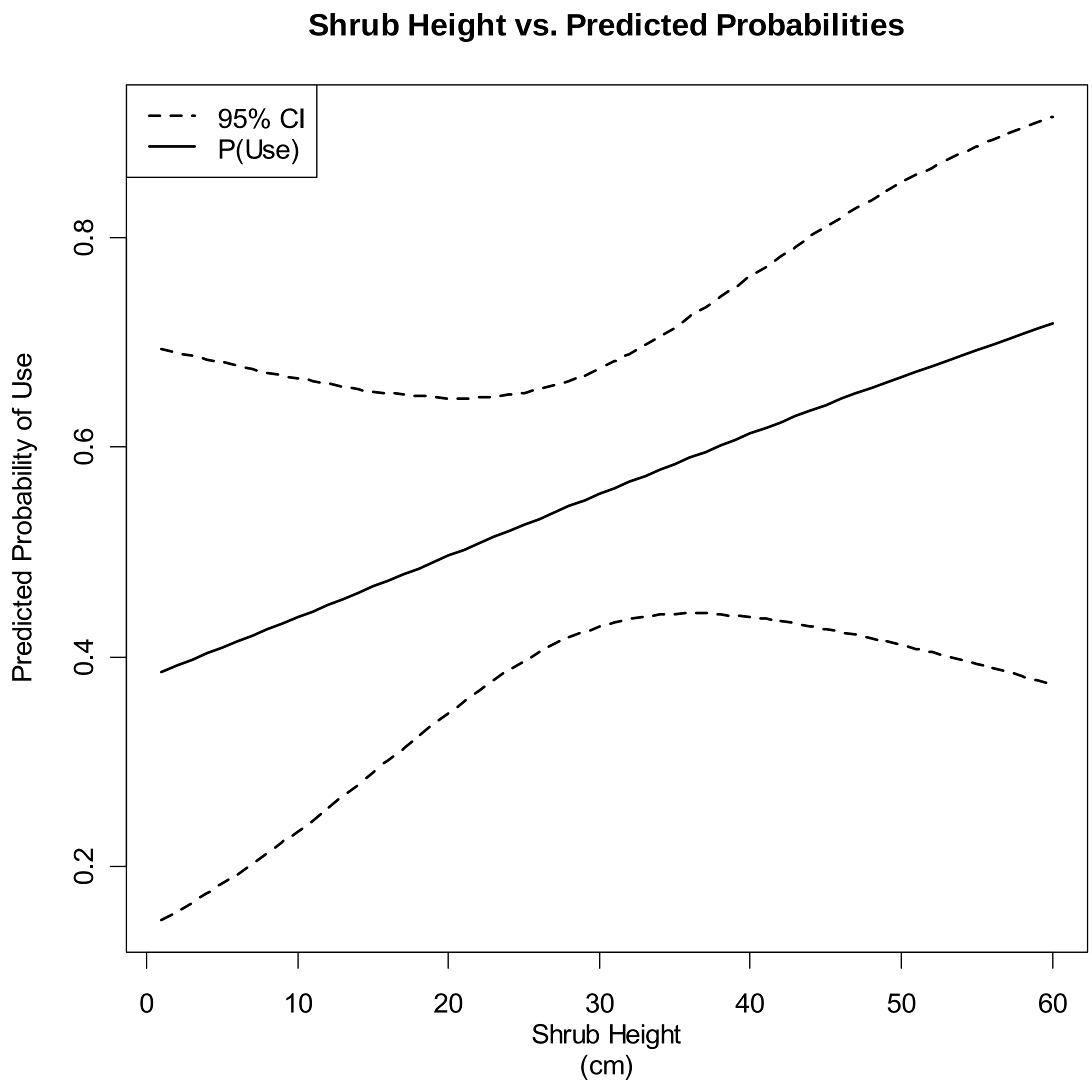

Figure 7c. Plot of predicted (relative) probabilities of use for different values of SHt calculated using the *a priori* model LSD + GHt + SHt. Values for SHt were allowed to vary while GHt and LSD were held constant at their respective means of 18.48 cm and 12452 shrubs/ha.

DISCUSSION

Lek Attendance, Trapping, & Radiomarking

The sage grouse population of southwestern Montana appeared to be small. But despite the difficulties I had with trapping and obtaining large sample sizes, I still achieved a sample adequate to develop new information regarding survival and habitat selection of male sage grouse in foothills/mid-elevation habitat, a setting that has received little attention. I observed low numbers of sage grouse (both males and females) attending leks as compared to other studies (Schroeder et al. 1999). Over the course of this study, I found that the only efficient trapping method was spotlighting; it was likely due to the low densities of sage grouse on trapping leks that walk-in traps and rocket netting were not successful. Even with the small sample sizes in this study, I gained new understanding regarding management of sage grouse and developed new hypotheses to be investigated in the future.

Survival

Although I hypothesized that male survival would vary by site, year, and season, the best approximating-model held survival constant throughout the year. This may have been due to several causes: 1) small sample sizes may have limited my ability to detect subtle temporal and spatial variation in survival, 2) movement of birds across sites may have hidden variation between sites, or 3) there simply may not have been differences in survival between sites, years, and seasons. The three study sites were, on average, 60 km apart and the telemetry flight data showed that some males did move between sites; other studies have shown sage grouse may travel over 100 km to different seasonal use areas (Patterson 1952, Connelly et al. 1994). The sage grouse populations of southwestern Montana may not be distinct from each other and survival is probably more affected by individual variation (e.g. body condition, average distance traveled annually) than by general site characteristics. Year did not seem to affect survival, but I think this was due to the short duration of the study and continuous drought conditions in the west since 1999 (Cook et al. 2004). I speculate that a study that examines survival over a longer period would probably show important variation in survival across years due to factors such as disease outbreaks or severe weather events (especially in winter, when sage grouse survival is generally high; Moynahan et al. 2006). I also found that allowing survival to vary by season did not fit the data well, and I suspect this was due to the small sample sizes in some seasons. Use of shorter and more even time intervals between telemetry flights would allow this question to be explored in more depth; however, this would most likely be cost-prohibitive and not defensible for such small sample sizes. The estimate of annual survival of males (0.34, SE=0.067) is comparable to that reported by Zablan et al. (2003; 0.37, SE=0.0069) for adult male sage grouse in North Park, Colorado, a site that seemed to be similar to southwestern Montana with regard to elevation and topography. Annual survival for this study was also similar to annual survival of females in central Montana (35 – 40%, Wallestad 1975). Due to the lek mating system (few males perform a vast majority of copulations, Hartzler and Jenni 1988) and absence of parental care (Wiley 1973), males are likely not limiting to the population growth rate, but declining numbers of males may still have indirect negative effects on the population. At small population sizes, lek-breeding species may exhibit Allee effects (Reed 1999) or the male population may simply become nonviable due to a lack of genetic diversity (Caughley 1994). Thus monitoring male survival and population size for southwestern Montana sage grouse may be important to their conservation.

Habitat selection

In keeping with my predictions, I found that grass height was an important predictor of habitat selection by male sage grouse. However, the negative relationship between the probability of a site being used and grass height was opposite of what I had predicted. Holloran (1999) found that areas used by male sage grouse near Casper, Wyoming in summer had statistically lower vertically-obstructing cover and suggested that the birds were choosing areas with greater forb cover and fewer residual grasses, and thus choosing areas with shorter grasses. This may be the case with the sage grouse of southwestern Montana as I was not able to determine whether grass height and forb cover were inversely correlated; thus, I could not eliminate Holloran's (1999) explanation for this result. However, sage grouse eat mostly sagebrush and it seems unlikely that the presence of forbs would drive habitat selection by sage grouse. A more likely reason for this result is confounding between the date a habitat plot was measured and grass height, therefore, further research is needed to determine whether grass height is an important predictor of habitat selection or a result of the sampling design. Due to the small sample size and confounding, I am skeptical of this result and do not want to make management recommendations because of my concerns.

Many of the use sites I measured were at lower elevation when compared with the available sites; these lower elevation areas were near leks and at two of the study sites (BSC and CV), 73% and 75% of the telemetry locations, respectively, were within 6.3 km of trap leks. I did not find an appreciable relationship between elevation and grass height (r = 0.21); this suggested that males were using habitat closer to leks and did not have to travel to higher elevations to find habitat that met their needs. In HP, where only 28% of the locations were within 6.3 km of trap leks, there was mostly bare ground between sagebrush plants, so the birds may have traveled farther from leks to find suitable habitat.

During the day, the risk of predation from aerial predators (e.g. Golden Eagles [*Aquila chrysaetos*]) is higher than from ground predators (e.g. coyotes [*Canis latrans*], J. W. Roscoe, pers. comm.), therefore, I expected sage grouse to use areas with greater over-head cover in the form of higher live shrub densities and shrub heights. I thought LSD and SHt would be important predictors of use because I modeled day use sites, but the effects of these variables on use were not statistically different from zero. This may have been a result of the small sample size in this study and the fact that I had to pool the study sites for analysis. Site-to-site variation may have been masked in this case and should be examined in the future to determine whether differences in habitat types between sites lead to differences in habitat selection. Due to the importance of sagebrush to sage grouse ecology, I think that it would be wise to examine use over a wider range of shrub densities and heights as such an analysis might yield different results and would certainly allow stronger inferences.

An important predictor of use in the exploratory analysis was solar radiation index. The negative effect of SRI on habitat selection may have been a result of sampling only during summer daylight hours. Birds often avoid heat by seeking shade and avoiding activity during the hottest part of the day (Gill 1990); the sage grouse may have been choosing areas that allowed them to efficiently thermoregulate during hot summer days. Steeper, north-facing slopes would have provided cooler areas in the form of a more acute solar angle and more shade; SRI may have acted as a proxy for microsite temperature. Other bird species, such as Sage Sparrows (Petersen and Best 1985), Burrowing Owls (*Speotyto cunicularia*; Coulombe 1971), and Spotted Owls (*Strix occindentalis*; Barrows 1981), also use sun avoidance behaviors during the summer.

Further Research and Management Implications

The reasons for the decline of the sage grouse population of southwestern Montana are still unclear. I observed few birds, especially females, on leks and found low rates of survival for males. I do not know why population size and survival are low, but I think continued research and monitoring are very important to the conservation of this population. To better understand how variation between individuals affects survival, it would be beneficial to gather individual data for each radio-marked bird including body measurements and age. Studies done over longer time periods and under varying conditions (e.g. non-drought conditions) may reveal trends in population fluctuations that may be too subtle to detect using short-term studies (Collins 2001). It may also be important to study male survival more intensely during seasons other than summer to understand what role, if any, other factors play in the dynamics of this population. Mortality of male sage grouse is generally higher during the spring (lekking season), possibly due to increased predation and to the physiological demands of displaying (Patterson 1952, Swenson 1986, Boyce 1990, Schroeder et al. 1999). Other periods that may result in lower survival are times when vulnerability to West Nile virus is high (late summer, Naugle et al. 2004), during the hunting season (Bergerud 1985, 1988), and during severe winters (Moynahan et al. 2006). It seems important for monitoring to continue year-round and to adjust management strategies based on seasonal causes of mortality.

One threat to sage grouse that has emerged in recent years is West Nile virus (WNv). Little or no testing has been done to confirm the presence of WNv or its extent in southwestern Montana. In a lab setting, Clark et al. (2006) documented 100% mortality in unvaccinated sage grouse, and in the field, Naugle et al. (2004) documented a 26% decrease in survival of sage grouse populations in which WNv was confirmed. If the virus is or becomes established in this area, it could have major consequences for the long-term conservation of the population. Also, I observed sage grouse moving closer to sources of water (e.g. springs and creeks) as temperatures increased in mid- and late-summer, which is the peak of mosquito production and WNv infection (Naugle et al. 2004), so this behavior may increase the extent and effect of WNv in southwestern Montana further exacerbating the decline of this population.

In this study, I examined habitat selection, but I was unable to determine whether areas with specific habitat attributes were preferred. More research is needed to determine the habitat preferences of sage grouse in southwestern Montana and whether these preferences confer higher rates of survival. However, in human-altered habitats, selection may not be adaptive; birds may not have the choice of selecting good habitat or may not select the settings where they do well. To figure this out, studies would need to look at survival and reproductive output across a gradient of landscapes in different conditions. Such work would be valuable but will necessitate working in areas with larger population sizes than were available in this study.

I found that male sage grouse used sites with shorter grasses, but further research is needed to determine whether sage grouse choose to use areas with shorter grasses, or if the results of this study were due to study design and confounding. Further study is also needed to determine what effect, if any, the use of areas with shorter grasses has on male sage grouse survival.

Although I found that shrub density and height did not have an effect on habitat selection, more work should be done over a wider range of densities and heights to see if greater variation in available habitat leads to certain preferences by sage grouse. My finding regarding SRI suggests that more research should be done on how habitat components relate to or interact with each other, habitat use (and, if possible, habitat selection) by sage grouse, and survival of sage grouse.

The composition of sagebrush in sage grouse habitat is important to increased nest and brood success (Patterson 1952, Klebenow 1969, Gregg et al. 1994, Woodward 2006). Male sage grouse may use areas different from breeding hens, so it may be important to study the habitat needs of both male and female sage grouse. This demonstrates the importance of studying and managing sagebrush habitats in a broad context over a wide variety of conditions. Therefore, it is important to keep sagebrush habitats that support stable sage grouse populations intact and to determine the habitat characteristics important to all aspects of sage grouse ecology.

In southwestern Montana, an area of promise for sage grouse conservation is the Centennial Valley. Lek counts from the western portion of the valley indicate the CV population is considerably larger than those in BSC and HP. The Centennial Valley also has large tracts of public land, the BLM manages a large portion of the land in the western end of the valley and the eastern end of the valley is dominated by Red Rock Lakes National Wildlife Refuge. This offers a unique situation for studying sage grouse population dynamics and conservation threats (e.g. hunted vs. unhunted, differing levels of grazing intensity, WNv).

Finally, any research and management actions that positively affect sage grouse will have positive effects on other sagebrush obligate species. Interest and concern for sage grouse and Pygmy rabbits continue to increase, and, with very similar habitat requirements, studying, protecting, and improving habitat for both species can be done in tandem, improving efficiency and leading to a greater understanding of sagebrush ecosystems and their inhabitants.

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APPENDICES

APPENDIX A

EXPLANATION AND CALCULATION

OF SOLAR RADIATION INDEX (SRI)

I used solar radiation index (SRI) to model slope and aspect without using indicator variables and to get around the problems associated with circular data. Circular data (e.g. compass bearings) do not have a true zero and thus low and high values are determined arbitrarily. Another problem is that the arithmetic mean of circular data is not meaningful. I did not want to use indicator variables to represent aspect because using cardinal and ordinal directions would have resulted in 7 dummy variables. This would have increased the number of variables used in my analysis by 50%. I decided to use SRI because it is calculated using both slope and aspect, along with latitude, to create one new variable. Solar radiation index is calculated as follows (adapted from Iqbal 1983:72):

SRI = cos[latitude] cos[slope] + sin[latitude] sin[slope] cos[transformed aspect],

where [transformed aspect] = 180 – aspect.

The resulting variable is on a scale from -1 to 1, with -0.7 representing a northerly, 90° slope; 0.71 a flat slope; and 1 a southerly, 45° slope. The average slope in this dataset was -6.4° (Fig. 8). Figure 8 also shows the SRI values for slopes of 0°, -15°, -30°, and -60°, respectively, at different aspects.

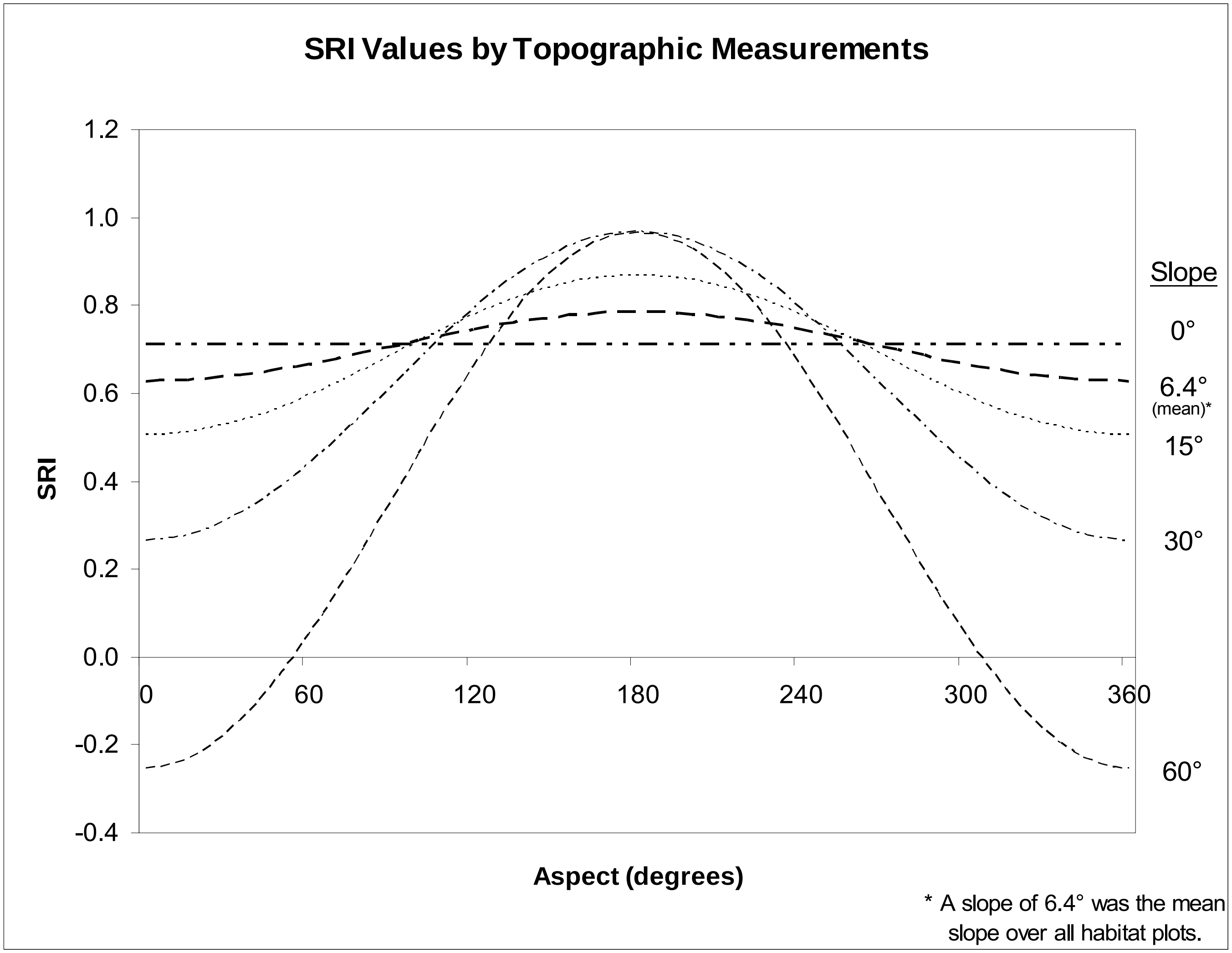

Figure 8. SRI values for different slopes and aspects. The average slope for this dataset was -6.4°.

APPENDIX B

PAIRS PLOTS AND CORRELATIONS

OF HABITAT PREDICTOR VARIABLES

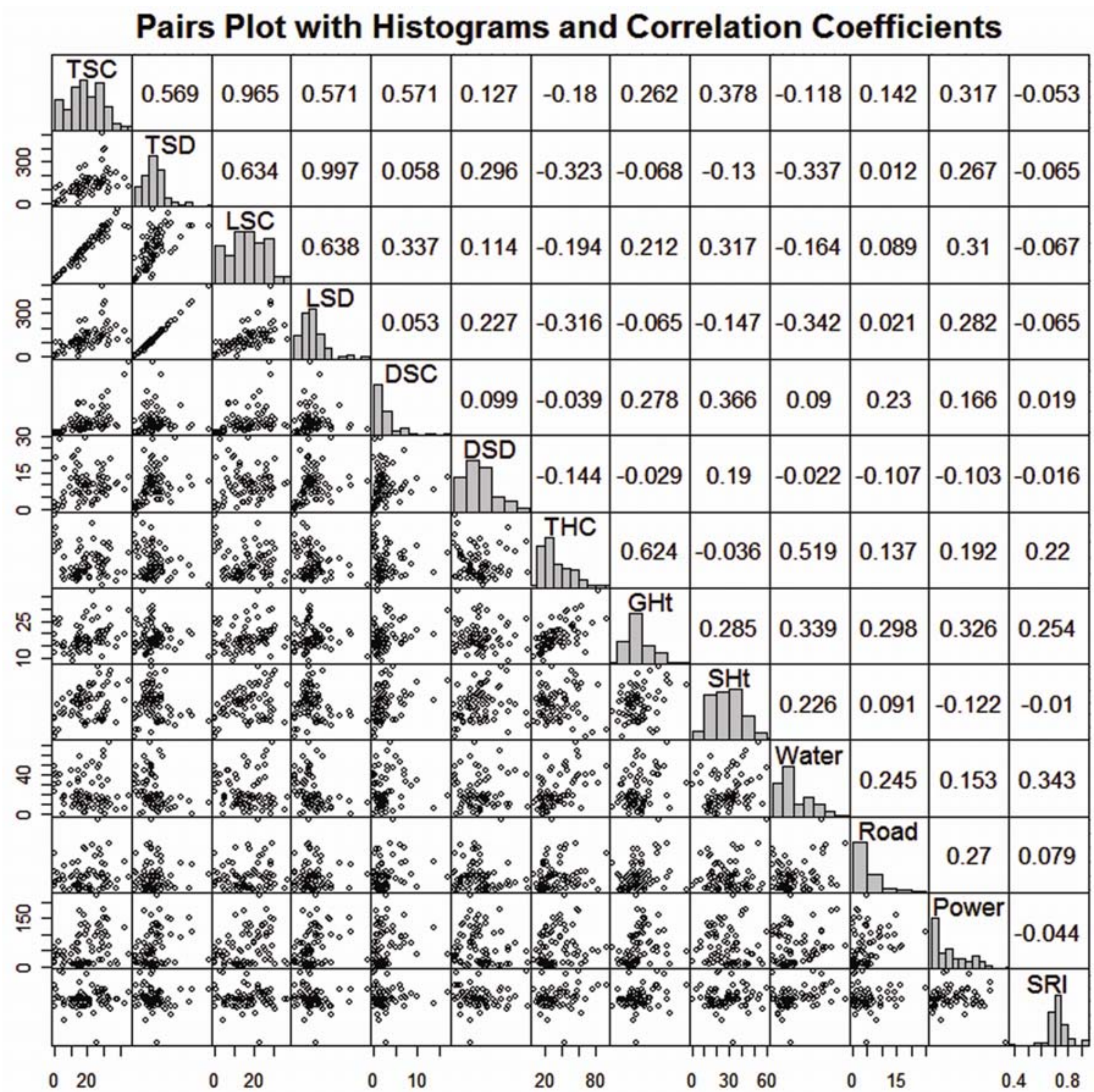

Figure 9. Pairs plots of habitat predictor variables with correlation coefficients and histograms of each respective predictor.

APPENDIX C

INPUT FILES FOR SURVIVAL AND HABITAT ANALYSES

Survival Input File for Program MARK

```
/*Bird(n=45)Encounter History (39 occassions)                                                     BSC   HP   CV*/
/*150.015*/ 101010101010110000000000000000000000000000000000000000000000000000000000000000   0    1    0;
/*150.073*/ 101010101010101011000000000000000000000000000000000000000000000000000000000000   0    1    0;
/*150.172*/ 001010101010101010101010101100000000000000000000000000000000000000000000000000   0    1    0;
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/*150.324*/ 101010101010101010101010101010101010001010110000000000000000000000000000000000   1    0    0;
/*150.425*/ 101011000000000000000000000000000000000000000000000000000000000000000000000000   1    0    0;
/*150.464*/ 101010101010101011000000000000000000000000000000000000000000000000000000000000   1    0    0;
/*150.483*/ 101010101010101010101100000000000000000000000000000000000000000000000000000000   1    0    0;
/*150.503*/ 101010101010110000000000000000000000000000000000000000000000000000000000000000   1    0    0;
/*150.523*/ 101010101010101100000000000000000000000000000000000000000000000000000000000000   1    0    0;
/*150.063*/ 000000000000000010101100000000000000000000000000000000000000000000000000000000   1    0    0;
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/*150.191*/ 000000000000000010101010101010101010110000000000000000000000000000000000000000   0    1    0;
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/*150.302*/ 000000000000000010101010101010101100000000000000000000000000000000000000000000   0    1    0;
/*150.425*/ 000000000000000010101010101010101100000000000000000000000000000000000000000000   0    1    0;
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/*150.503*/ 000000000000000010101010101010110000000000000000000000000000000000000000000000   1    0    0;
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/*151.039*/ 000000000000000000000000000000000000000010101010110000000000000000000000000000   1    0    0;
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/*151.068*/ 000000000000000000000000000000000000000000000000000000000000101010101100000000   0    1    0;
/*150.513*/ 000000000000000000000000000000000000000000000000000000000000101100000000000000   0    1    0;
/*150.003*/ 000000000000000000000000000000000000000000000000000000000000000000101100000000   0    0    1;
/*150.015*/ 000000000000000000000000000000000000000000000000000000000000000000101010101010   0    0    1;
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/*150.382*/ 000000000000000000000000000000000000000000000000000000000000000000101100000000   0    0    1;
```

99

```
/*150.704*/ 000000000000000000000000000000000000000000000000000000000000000000101100000000   0    0    1;
/*150.726*/ 000000000000000000000000000000000000000000000000000000000000000000101010110000   0    0    1;
/*150.746*/ 000000000000000000000000000000000000000000000000000000000000000000101010101010   0    0    1;
/*150.764*/ 000000000000000000000000000000000000000000000000000000000000000000101011000000   0    0    1;
/*150.786*/ 000000000000000000000000000000000000000000000000000000000000000000101010101000   0    0    1;
/*150.807*/ 000000000000000000000000000000000000000000000000000000000000000000101010101010   0    0    1;
/*150.845*/ 000000000000000000000000000000000000000000000000000000000000000000101010101010   0    0    1;
/*150.866*/ 000000000000000000000000000000000000000000000000000000000000000000101010101011   0    0    1;
/*150.905*/ 000000000000000000000000000000000000000000000000000000000000000000101011000000   0    0    1;
/*150.945*/ 000000000000000000000000000000000000000000000000000000000000000000101010101000   0    0    1;
/*150.965*/ 000000000000000000000000000000000000000000000000000000000000000000101011000000   0    0    1;
/*150.986*/ 000000000000000000000000000000000000000000000000000000000000000000101010101010   0    0    1;
/*151.121*/ 000000000000000000000000000000000000000000000000000000000000000000101011000000   1    0    0;
```

Habitat Input File for R

(* indicates variables that were rescaled, original variable = var* x 100)

ID	Use	HP	CV	Site	TSC	TSD*	LSC	LSD*	DSC	DSD*	HCan	THC	GHt	SHt	Water*	Road*	Power*	SRI
1	1	0	0	BS	15.40	117.19	14.29	92.50	1.11	11.67	4.59	17.42	12.27	32.24	20.04	3.45	12.48	-0.925
2	1	0	0	BS	11.09	81.39	10.61	75.56	0.48	5.83	4.37	16.06	11.15	30.61	17.32	4.89	5.30	-0.954
3	1	0	0	BS	21.35	86.11	19.26	76.39	2.09	9.72	5.14	16.00	11.97	43.94	15.71	0.39	9.38	0.933
4	1	0	0	BS	21.01	88.61	18.36	77.78	2.64	10.83	5.82	17.58	15.52	46.06	11.96	1.55	5.07	-0.919
5	1	0	0	BS	29.29	506.67	28.54	495.28	0.76	11.39	3.06	7.00	10.42	14.73	11.29	5.47	18.36	-0.431
6	1	0	0	BS	9.51	81.39	7.86	72.22	1.65	9.17	5.11	17.42	11.75	37.28	30.36	0.27	16.60	-0.764
7	1	0	0	BS	15.06	120.56	13.41	114.44	1.65	6.11	8.21	21.21	15.15	32.79	12.22	0.11	4.35	0.651
8	1	0	0	BS	5.16	72.50	5.06	68.06	0.10	4.44	4.48	25.45	14.59	33.69	15.31	5.21	3.84	-0.686
9	1	1	0	HP	27.66	143.61	25.87	130.00	1.79	13.61	7.52	14.45	17.97	54.76	37.10	0.26	22.06	0.389
10	1	1	0	HP	33.99	210.83	31.03	190.00	2.97	20.83	10.35	50.91	22.97	57.12	10.03	2.13	5.97	-0.895
11	1	0	0	BS	12.91	102.78	11.57	87.50	1.34	15.28	7.92	18.59	14.67	32.21	9.71	1.49	7.31	-0.674
12	1	1	0	HP	15.47	70.56	15.03	63.89	0.43	6.67	6.36	60.45	20.42	41.09	57.86	2.12	175.49	-0.615
13	1	0	0	BS	11.75	125.28	10.31	103.33	1.44	21.94	7.46	24.39	15.33	31.12	9.85	1.68	8.20	-0.764
14	1	0	0	BS	14.99	139.17	12.80	121.67	2.19	17.50	6.92	23.79	17.36	43.12	10.30	0.66	1.83	0.935
15	1	0	0	BS	38.83	126.11	37.53	115.28	1.30	10.83	6.58	21.41	17.94	44.73	16.47	3.48	8.54	-0.835
16	1	0	0	BS	0.10	4.72	0.10	4.44	0.00	0.28	10.66	67.88	19.61	16.79	39.34	6.75	34.57	-0.926
17	1	0	0	BS	21.47	180.28	19.24	169.44	2.23	10.83	5.90	28.59	14.64	37.00	18.31	0.18	11.98	-0.963
18	1	1	0	HP	29.98	178.06	26.84	159.72	3.13	18.33	8.15	58.33	18.12	43.58	63.37	1.78	176.47	-0.673
19	1	1	0	HP	5.86	87.50	4.89	71.11	0.96	16.39	4.92	13.39	11.33	21.67	17.30	0.06	46.96	-0.342
20	1	1	0	HP	14.62	129.72	13.64	118.33	0.98	11.39	6.30	13.82	14.58	28.94	16.61	0.34	47.34	-0.246
21	1	0	0	BS	20.79	151.11	18.63	139.72	2.17	11.39	5.70	28.48	16.21	31.67	16.48	5.13	7.27	-0.440
22	1	1	0	HP	11.16	119.44	9.22	98.06	1.93	21.39	6.42	18.06	8.61	22.33	7.47	9.65	59.38	-0.059
23	0	0	0	BS	9.82	108.33	6.77	95.83	3.04	12.50	4.75	27.27	13.91	18.94	43.30	4.65	37.07	-0.920
24	0	0	0	BS	14.12	4.17	11.31	3.89	2.81	0.28	5.57	17.06	12.67	20.73	36.08	0.13	21.64	0.970
25	0	0	0	BS	13.93	155.28	12.93	136.39	1.01	18.89	5.46	22.58	15.06	28.48	20.42	1.25	0.68	0.936
26	0	0	0	BS	19.67	183.06	17.29	169.44	2.38	13.61	5.54	32.12	18.36	34.79	19.49	5.31	10.06	0.694
27	0	0	0	BS	16.06	47.22	12.49	41.67	3.56	5.56	5.40	23.48	15.52	29.30	22.20	4.48	6.73	-0.046
28	0	0	0	BS	1.11	114.17	1.11	92.78	0.00	21.39	8.46	75.91	24.06	4.33	41.21	3.21	52.34	0.309
29	0	0	0	BS	5.87	25.00	5.38	22.22	0.49	2.78	7.93	41.21	14.33	24.73	17.74	3.36	10.75	0.748
30	0	0	0	BS	2.99	130.00	2.78	101.39	0.21	28.61	9.51	59.09	25.82	21.67	39.07	3.35	46.09	-0.650

ID	Use	HP	CV	Site	TSC	TSD*	LSC	LSD*	DSC	DSD*	HCan	THC	GHt	SHt	Water*	Road*	Power*	SRI
31	0	1	0	HP	13.78	132.22	12.68	119.72	1.11	12.50	3.84	11.48	18.15	32.91	14.17	2.04	50.63	-0.418
32	0	1	0	HP	26.49	114.72	21.99	95.83	4.49	18.89	6.55	28.33	26.73	60.06	47.25	24.92	109.70	0.554
33	0	0	0	BS	4.62	40.00	4.57	38.89	0.04	1.11	4.09	17.52	14.97	20.55	0.41	1.32	34.82	0.859
34	1	0	0	BS	0.14	1.39	0.00	0.56	0.14	0.83	12.15	67.27	12.33	0.73	29.78	1.71	16.14	-0.933
35	1	0	0	BS	18.55	279.17	17.18	250.00	1.37	29.17	4.01	22.27	13.09	10.70	6.78	0.66	9.63	-0.228
36	1	0	1	CV	29.02	315.28	22.62	307.50	6.40	7.78	6.47	38.79	16.21	19.33	16.47	9.34	90.39	-0.675
37	1	0	1	CV	24.46	186.11	22.82	182.22	1.64	3.89	5.35	38.18	16.70	14.24	12.67	12.04	93.32	-0.036
38	1	0	0	BS	17.41	102.78	14.80	91.39	2.61	11.39	7.52	32.12	16.30	38.33	11.24	1.71	4.02	-0.756
39	1	0	1	CV	26.65	163.06	24.42	159.44	2.23	3.61	6.02	42.58	20.42	18.64	9.74	4.58	129.24	-0.088
40	1	0	1	CV	29.93	380.56	28.95	367.78	0.98	12.78	6.91	30.30	20.61	22.42	12.25	0.80	149.95	0.406
41	1	0	1	CV	31.64	233.89	28.96	228.61	2.68	5.28	6.56	35.15	21.15	26.48	11.89	2.66	150.73	0.789
42	1	0	1	CV	20.11	167.78	18.79	160.83	1.32	6.94	5.38	29.85	18.03	14.42	7.39	4.86	124.89	0.630
43	1	0	0	BS	13.58	110.83	11.28	97.50	2.30	13.33	5.34	28.79	17.12	28.00	14.66	5.00	1.97	-0.828
44	1	0	0	BS	0.18	8.06	0.14	5.28	0.04	2.78	5.67	47.42	16.39	17.42	21.87	2.82	11.92	-0.902
45	1	0	0	BS	1.24	6.67	1.24	6.67	0.00	0.00	8.65	57.88	15.33	28.21	38.43	6.16	33.61	0.651
46	1	0	1	CV	18.87	151.11	17.91	147.22	0.96	3.89	5.88	38.33	18.67	13.12	17.25	0.39	136.10	0.174
47	1	0	1	CV	25.66	151.67	22.68	144.72	2.97	6.94	5.85	43.64	17.76	32.73	18.09	4.97	221.12	0.875
48	1	0	0	BS	17.44	193.06	15.63	180.00	1.81	13.06	4.69	23.79	17.12	13.97	9.80	1.45	7.94	-0.783
49	1	0	0	BS	5.74	79.17	4.53	72.50	1.21	6.67	4.59	23.18	16.36	24.58	9.29	8.30	27.08	-0.725
50	1	0	1	CV	32.21	253.33	30.41	244.72	1.80	8.61	6.59	38.18	21.06	23.52	15.10	5.30	147.50	0.782
51	1	0	1	CV	0.25	6.67	0.14	6.39	0.11	0.28	12.53	92.73	25.67	7.58	48.93	12.98	58.97	0.855
52	0	0	0	BS	33.33	111.39	29.61	103.06	3.72	8.33	10.53	57.12	29.82	53.52	71.79	16.56	64.04	0.069
53	0	0	0	BS	27.06	117.78	25.76	108.89	1.30	8.89	5.49	42.73	16.39	36.24	49.63	14.24	49.51	-0.328
54	1	0	1	CV	16.41	128.06	15.98	118.61	0.43	9.44	7.20	53.48	22.45	24.58	17.67	4.86	131.43	-0.797
55	0	0	0	BS	23.77	121.39	20.84	111.11	2.92	10.28	10.44	63.48	31.00	46.18	5.15	6.43	4.97	-0.088
56	0	0	1	CV	2.48	25.28	2.40	23.89	0.08	1.39	5.22	52.73	23.33	7.42	31.19	3.34	78.66	-0.750
57	0	0	1	CV	21.26	174.44	20.26	167.78	0.99	6.67	5.05	29.09	16.61	26.21	15.12	7.22	75.93	0.888
58	0	0	1	CV	28.85	158.89	26.78	142.78	2.07	16.11	5.38	26.36	20.67	15.85	6.83	6.14	102.22	0.668
59	0	0	1	CV	18.75	165.00	18.18	157.22	0.57	7.78	5.07	23.03	18.18	13.39	0.47	14.45	98.12	0.609
60	0	0	1	CV	27.33	149.72	25.91	137.22	1.42	12.50	5.87	33.79	20.94	16.76	15.80	0.09	133.06	-0.556
61	0	0	0	BS	37.51	226.94	35.67	216.67	1.83	10.28	4.20	11.81	14.70	13.36	4.71	0.78	16.75	-0.898
62	0	0	0	BS	23.36	59.44	22.42	58.06	0.94	1.39	12.50	82.27	37.47	44.44	31.46	0.30	45.34	-0.769
63	0	0	0	BS	32.92	86.67	23.08	74.17	9.83	12.50	11.57	54.39	21.18	47.61	33.52	1.06	36.50	0.360

ID	Use	HP	CV	Site	TSC	TSD*	LSC	LSD*	DSC	DSD*	HCan	THC	GHt	SHt	Water*	Road*	Power*	SRI
64	0	0	1	CV	30.56	395.28	28.72	385.83	1.84	9.44	4.18	19.09	19.73	19.00	0.04	9.17	107.81	0.858
65	0	0	1	CV	15.16	249.72	14.26	247.22	0.90	2.50	4.85	15.45	17.79	19.18	6.16	1.37	98.08	0.514
66	0	0	1	CV	23.49	90.56	17.47	87.78	6.03	2.78	5.75	44.39	25.21	33.58	51.90	16.07	58.21	0.711
67	0	0	0	BS	18.12	60.00	15.34	57.50	2.78	2.50	4.85	22.12	17.97	29.52	1.08	3.93	14.01	-0.366
68	0	0	0	BS	29.88	197.78	24.92	190.83	4.96	6.94	5.28	22.88	17.88	15.48	57.57	4.09	59.44	0.448
69	0	1	0	HP	19.99	120.00	16.78	110.28	3.21	9.72	5.78	44.85	28.64	31.91	48.00	0.79	114.29	0.704
70	0	0	1	CV	28.58	158.33	24.09	148.06	4.48	10.28	5.57	22.27	19.79	15.12	2.03	12.34	125.26	0.914
71	1	0	1	CV	32.47	152.78	26.25	144.17	6.22	8.61	4.20	16.52	15.64	29.12	7.20	3.32	96.81	-0.747
72	0	0	1	CV	29.11	140.83	20.49	133.89	8.62	6.94	4.69	32.73	18.36	36.91	28.73	5.80	73.08	0.563
73	1	0	1	CV	42.62	182.78	28.74	175.00	13.87	7.78	5.54	21.67	19.88	31.52	6.00	9.91	122.75	-0.444
74	0	0	0	BS	45.31	122.22	28.36	108.89	16.95	13.33	5.23	46.21	29.64	48.73	17.63	4.37	36.51	-0.492
75	0	1	0	HP	14.53	89.44	7.24	78.89	7.29	10.56	4.39	19.09	17.52	36.00	31.88	9.80	95.91	-0.698
76	0	1	0	HP	14.16	63.61	7.27	39.44	6.89	24.17	7.73	46.97	19.09	28.21	44.32	2.38	73.86	-0.952
77	0	1	0	HP	13.36	69.72	9.32	62.22	4.03	7.50	4.03	15.67	22.76	35.12	23.02	6.56	74.57	-0.430
78	0	0	1	CV	17.83	116.94	10.79	107.22	7.03	9.72	5.58	38.79	26.27	39.52	39.76	15.07	159.86	0.129

The response variable for logistic regression analysis was “Use” where 1 = used and 0 = available.

APPENDIX D

NEST AND BROOD HABITAT DATA

Table 8. General information about nest and brood habitat plots. UTM coordinates are for zone 12T.

ID#	Year	Date	Site	UTM Easting	UTM Northing	Plot Type	Nest Fate	Fate Date	Number/ Date [a]	Aspect	Slope
NB1	2004	27-May	BSC	349607	4938339	nest	failed--depredated	5/24/2004	401	180	0
NB 2	2004	2-Jun	BSC	344364	4939374	nest	failed--depredated	5/29/2004	402	0	0
NB 3	2004	22-Jun	BSC	347977	4937956	nest	depredated		403		0
NB 4	2004	17-Jun	BSC	346620	4938675	brood	hatched	6/12/2003	6/19/2003		
NB 5	2004	17-Jun	BSC	348087	4937629	brood	hatched	6/12/2003	6/27/2003		
NB 6	2005	15-Jul	Cent	398655	4935077	brood			7/11/2005	239	-11
NB 7	2005	15-Jul	Cent	402200	4935116	brood			7/15/2005		
NB 8	2005	20-Jul	BSC	346146	49939659	nest	depredated		501	78	-2
NB 9	2005	24-Jul	Cent	397537	4952039	brood			7/21/2005	304	-10
NB 10	2005	29-Jul	Cent	399041	4935171	brood			7/21/2005	186	-11
NB 11	2005	29-Jul	Cent	398641	4935157	brood			7/29/2005	225	-13
NB 12	2005	13-Aug	Cent	395069	4943119	brood			8/10/2005		

[a] Nest number or Brood observation date.

Table 9. Measurements taken at each nest shrub.

ID# (nests only)	Species (nest shrub)	Conceal		Nest Shrub				Grass Height
		Species 1	Species 2	Height	Max Width	Perp Width	Vigor (%)	
NB 1	Artemisia arbuscula	Artemisia arbuscula	n/a	38	120	80	75	11
NB 2	Potentilla fruticosa	Juncus spp.	Allium spp.	90	123	115	30	18
NB 3	Potentilla fruticosa	Potentilla fruticosa	Juncus spp.	111	214	151	100	36
NB 8	Artemisia tridentata wyomingensis	Artemisia tridentata	Chrysothamnus nauseosus	84	180	166	90	26

Table 10. Percent shrub cover for each nest/brood plot.

ID#	Species	Percent Cover Live	Percent Cover Dead
1	Artemisia arbuscula	0.14	--
2	Potentilla fruticosa	0.22	--
2	Salix spp.	0.00	--
3	Potentilla fruticosa	0.08	--
4	Chrysothamnus nauseosus	0.00	--
5	Artemisia arbuscula	0.07	0.01
5	Chrysothamnus nauseosus	0.06	0.01
5	Chrysothamnus viscidiflorus	0.00	--
6	Artemisia tripartita tripartita	0.14	--
6	Chrysothamnus viscidiflorus	0.00	--
6	Tetradymia canescens	0.02	--
7	Artemisia tripartita tripartita	0.04	--
7	Tetradymia canescens	0.00	--
8	Artemisia tridentata wyomingensis	0.17	0.04
8	Chrysothamnus nauseosus	0.01	--
8	Tetradymia canescens	0.00	--
9	Artemisia tridentata vaseyana	0.31	0.01
9	Chrysothamnus viscidiflorus	0.01	--
10	Artemisia tripartita tripartita	0.22	0.01
10	Tetradymia canescens	0.01	--
11	Artemisia tripartita tripartita	0.21	0.00
11	Chrysothamnus viscidiflorus	0.01	0.01
11	Tetradymia canescens	0.02	0.00
12	Artemisia nova	0.26	--
12	Artemisia tridentata wyomingensis	0.00	--
12	Artemisia tripartita tripartita	0.00	0.02
12	Chrysothamnus nauseosus	0.02	0.01
	Mean	0.08	0.01
	Standard Deviation	0.10	0.01

Table 11. Live and dead shrub densities for each nest/brood plot.

ID #	Species	Live (shrubs/ha)	Dead (shrubs/ha)
1	Artemisia arbuscula	19655.17	5258.62
1	Chrysothamnus nauseosus	344.83	--
2	Potentilla fruticosa	11637.93	344.83
2	Salix spp.	689.66	--
3	Potentilla fruticosa	2413.79	86.21
4	Chrysothamnus nauseosus	344.83	--
5	Artemisia arbuscula	5862.07	172.41
5	Chrysothamnus nauseosus	6379.31	86.21
6	Artemisia tripartita tripartita	8534.48	86.21
6	Chrysothamnus viscidiflorus	1206.90	--
6	Tetradymia canescens	775.86	--
7	Artemisia tripartita tripartita	6896.55	258.62
7	Chrysothamnus viscidiflorus	172.41	--
7	Tetradymia canescens	689.66	--
8	Artemisia tridentata wyomingensis	6810.34	517.24
8	Chrysothamnus nauseosus	862.07	172.41
8	Chrysothamnus viscidiflorus	862.07	--
8	Tetradymia canescens	517.24	--
9	Artemisia cana	172.41	--
9	Artemisia tridentata vaseyana	6120.69	172.41
9	Artemisia tripartita tripartita	86.21	--
9	Chrysothamnus viscidiflorus	603.45	--
10	Artemisia tripartita tripartita	10689.66	258.62
10	Chrysothamnus viscidiflorus	344.83	--
10	Tetradymia canescens	2931.03	--
11	Artemisia tripartita tripartita	6896.55	344.83
11	Chrysothamnus viscidiflorus	1551.72	--
11	Tetradymia canescens	1724.14	--
12	Artemisia nova	11206.90	517.24

Table 11 continued.

12	Artemisia tridentata wyomingensis	1293.10	--
12	Artemisia tripartita tripartita	172.41	--
12	Chrysothamnus nauseosus	2586.21	603.45
12	Chrysothamnus viscidiflorus	344.83	--
	Mean	3678.16	269.07
	Standard Deviation	4595.86	912.52

Table 12. Means and standard deviations of shrub heights for each nest/brood plot.

ID #	Species	Mean	SD
1	Artemisia arbuscula	22.50	11.17
2	Potentilla fruticosa	49.70	16.37
3	Potentilla fruticosa	52.05	37.52
4	Chrysothamnus nauseosus	38.80	12.66
5	Artemisia arbuscula	40.63	11.73
5	Chrysothamnus nauseosus	43.90	8.62
6	Chrysothamnus viscidiflorus	20.00	2.65
6	Tetradymia canescens	25.00	7.07
6	Artemisia tripartita tripartita	37.80	12.97
7	Artemisia tripartita tripartita	14.70	4.04
7	Tetradymia canescens	19.00	0.00
8	Artemisia tridentata wyomingensis	40.33	14.43
8	Chrysothamnus nauseosus	33.00	11.60
9	Artemisia tripartita tripartita	28.00	0.00
9	Artemisia tridentata vaseyana	55.94	15.72
9	Chrysothamnus viscidiflorus	23.33	1.53
10	Artemisia tripartita tripartita	34.41	8.02
10	Tetradymia canescens	20.00	9.90
10	Chrysothamnus viscidiflorus	19.00	0.00
11	Artemisia tripartita tripartita	44.40	9.40
12	Chrysothamnus nauseosus	44.17	10.68
12	Artemisia nova	20.50	4.82

Table 13. Percent herbaceous canopy cover for each nest/brood plot.

ID #	Mean	SD
1	15.75	13.01
2	41.05	32.16
3	86.25	23.05
4	42.75	14.55
5	25.26	10.20
6	51.50	13.77
7	38.00	8.80
8	22.73	10.23
9	77.50	18.81
10	28.25	15.15
11	48.00	16.09
12	26.25	13.17
overall	41.14	22.55

Table 14. Grass heights (in cm) for each nest/brood plot. Heights shown in mean ± SD.

ID #	Grass Height	Inflorescence Height
1	12.60 ± 2.66	2.30 ± 5.05
2	11.55 ± 5.56	7.85 ± 8.08
3	30.95 ± 5.86	7.30 ± 10.37
4	17.10 ± 5.08	10.90 ± 4.70
5	16.85 ± 6.58	6.70 ± 9.26
6	15.95 ± 4.47	43.75 ± 15.28
7	13.15 ± 2.23	35.20 ± 6.70
8	13.63 ± 8.61	27.94 ± 16.19
9	26.70 ± 9.49	50.75 ± 8.54
10	16.95 ± 8.73	42.60 ± 9.38
11	18.00 ± 6.22	47.90 ± 12.44
12	20.60 ± 4.75	38.90 ± 10.79